AD615640

AD615640

P.S.D.C.—TR.—6
1 APRIL, 1965

OFFICE OF
CIVIL DEFENSE

BEST AVAILABLE COPY

CORPS OF ENGINEERS
U.S. ARMY

TECHNICAL REPORT

EVALUATION OF 200—PERSON SHELTER (VENTILATION)

DDC

PROTECTIVE STRUCTURES DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

PSDC-TR-6

EVALUATION OF 200-PERSON SHELTER (VENTILATION)

1 April 1965

OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication.

Prepared By

PROTECTIVE STRUCTURES DEVELOPMENT CENTER
JOINT CIVIL DEFENSE SUPPORT GROUP
OFFICE OF THE CHIEF OF ENGINEERS/BUREAU OF YARDS AND DOCKS

For

OFFICE OF CIVIL DEFENSE

PREFACE

This report, presenting an evaluation of the thermal environment and distribution of ventilation air in the basement portion of a 200-Person Fallout Shelter when supplied with a minimum rate of ventilation air, was authorized and funded by Office of Civil Defense Work Order No. OS-63-148 dated 24 May 1963 and as amended.

Tests by the Protective Structures Development Center were conducted concurrently with Office of Civil Defense sponsored ventilation studies performed on the same shelter by the University of Florida.

The period covered by this report is 29 September to 11 October 1963.

The study was made at the 200-Person Shelter located at the Protective Structures Development Center (PSDC), Fort Belvoir, Virginia, a part of the Joint Civil Defense Support Group managed by the Corps of Engineers, U.S. Army, and the Bureau of Yards and Docks, U.S. Navy.

Major Wilbur L. Cox
Chief, Protective Structures Development Center

Michael M. Dembo
Chief, Structures and Equipment Development Section

This report was prepared by O. W. Svaeri, Mechanical Engineer.

CONTENTS

LIST OF FIGURES AND TABLES

SUMMARY

Observations were made of the thermal environment in the basement portion of a box shaped reinforced concrete 200 person shelter when the shelter was supplied with a minimum quantity of ventilation air. Also, an evaluation was made of the distribution of the ventilation air in the shelter as measured by variations in effective temperature, when the air was supplied through a duct system and through a single point source.

Ventilation air conditioned to simulate a 1% design day in the Washington, D.C. area (i.e. air at dry bulb and wet bulb temperatures which will not be exceeded more than 1% of the time), was supplied to the shelter area tested. Approximately 100 simulated occupants (SIMOCS) were placed in the shelter basement to generate the same amount of heat and moisture as 100 human occupants.

When conditioned air was supplied at a minimum rate of 3 cfm per person, effective temperatures (ET) as high as 90 deg were attained and maintained within the shelter. Based on current standards for the thermal environment in shelters, it is concluded that a minimum ventilation rate of 3 cfm is not adequate for cooling this shelter space.

Ventilation air was delivered to the shelter by single point air delivery through a single opening in the basement ceiling, and through existing duct system. The temperature stratification in this small shelter was considerable when air was delivered through a single point, and effective temperatures between the opposite sides of the shelter differed as much as 4 degrees. When ventilation air was introduced into the shelter through a single inlet opening it was noted that air quantities supplied did not have a marked influence on the temperature stratification within the shelter. At ventilation rates up to 18 cfm effective temperature differences as large as $1\frac{1}{2}$-2 deg existed, due to short circuiting of air between the inlet and exhaust openings.

When ventilation air was delivered through the existing duct work the temperature stratification did not exceed 1 to 2 deg effective temperature even when the air was supplied at a minimum rate of 3 cfm per occupant.

It is concluded that ventilation air supplied at the rate of 3 cfm per person and conditioned to represent a 1% summer design day in the Washington, D.C. area would be inadequate to maintain a tolerable thermal environment in the shelter.

SECTION 1: INTRODUCTION

Objectives

1. The purpose of the tests described in this report was to evaluate the thermal environment of the basement of the 200-Person Shelter at the Protective Structures Development Center when provided with minimum ventilation. The evaluation was to be accomplished by (a) examining the effect of a 3 cfm per person minimum ventilation rate on the effective temperature in the occupied shelter during hot summer weather, and by (b) determining the air distribution obtained in the shelter using the existing duct work and a single point air delivery.

Background

2. In September 1963, tests for determination of optimum ventilation rates were conducted in the basement of the 200-Person Shelter located at the Protective Structures Development Center (PSDC) by the University of Florida under contract with the Office of Civil Defense (OCD). These tests were part of a nationwide series of evaluations of ventilation characteristics of survival shelters. The PSDC was authorized to conduct the study described in this report as an extension of the University of Florida contract.

3. An important factor in upgrading of existing and design of new shelter spaces is the provision of adequate ventilation air for heat and moisture removal and maintenance of an adequate air chemical environment. Current recommendations for these items are: (a) maximum 85 deg effective temperature as defined in chapter 8 of the ASHRAE Guide and Data Book,[1] (b) at least 17% oxygen, (c) a maximum of 1½% carbon dioxide, and a maximum of .01% carbon monoxide.[2] These figures are not established criteria, but vary depending on conditions peculiar to the environment, location, duration of shelter occupancy, and state of health of the shelter occupants. The provision of 3 cfm per person ventilation air as recommended by current engineering guides, such as OCD TM 61-3[3] and PG-80-10[4], "Catalog of Shelter Components", may not be sufficient in many areas in the United States during hot summer months to maintain an adequate thermal environment. This report evaluates the suitability of a 3 cfm per person ventilation rate for the 200-Person Shelter at the PSDC in relation to the maintenance of a maximum effective temperature of 85 deg within the shelter.

*Raised numbers refer to similarly numbered items in List of References.

4. In addition to investigating the effect of a 3 cfm per person ventilation rate, studies were made to measure the variations in effective temperatures throughout the shelter when using two different methods of supplying and distributing the ventilation air.

SECTION 2: INVESTIGATION

Description of Shelter

5. The 200-Person Shelter at the Protective Structures Development Center is a two-story reinforced concrete structure, approximately 37 feet square with one story below grade and the other at grade level. Ceiling height is approximately 10 feet. It is a dual purpose shelter equipped with an air conditioning system (cooling and heating) complete with a two zone distribution duct work for normal use, i.e., one zone for each of the stories. For emergency use a 4100 cfm blower is provided which supplies filtered fresh air to the upper story through a single inlet grille mounted high in a partition wall on the 1st floor and to the basement shelter area through a single centrally located outlet opening in the ceiling. Figure No. 1 shows an exterior view of the shelter. Figure No. 2 shows the floor plans and elevations of the shelter, including the air conditioning system duct work, major dimensions, and the locations of the inlets and outlets for the emergency air distribution system.

6. The shelter is located in a rural area, unshaded, in an open field with grass cover. The soil in the immediate vicinity of the shelter, primarily backfill material, is generally a coarse to fine graded sand, with strata of clayey or silty sands. A one-foot thick gravel blanket was, according to the engineering drawings, to be provided all around the basement walls (see section view, Figure No. 2). However, as noted subsequently, this gravel fill was found to be missing on certain of the walls with resultant local variations in temperatures and heat transfer. (See "Factors Affecting Heat Transfer" in the Discussion section of the report.)

Test Procedure

7. Only the below grade (basement) portion of the shelter was included in this study. Simulated occupants, as described hereinafter, were placed in the 25'-6" x 37'-0" area shown cross-hatched

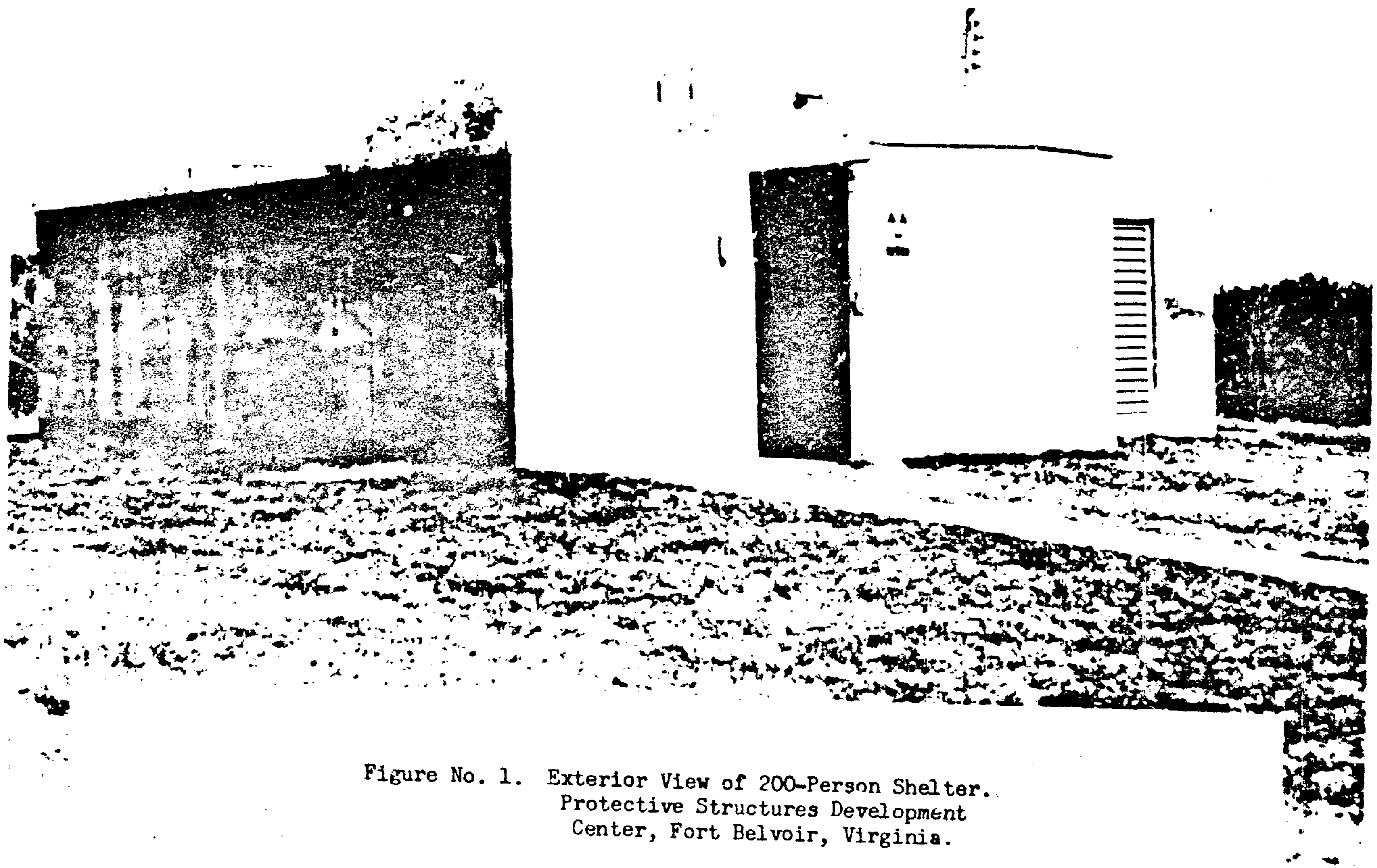


Figure No. 1. Exterior View of 200-Person Shelter. Protective Structures Development Center, Fort Belvoir, Virginia.

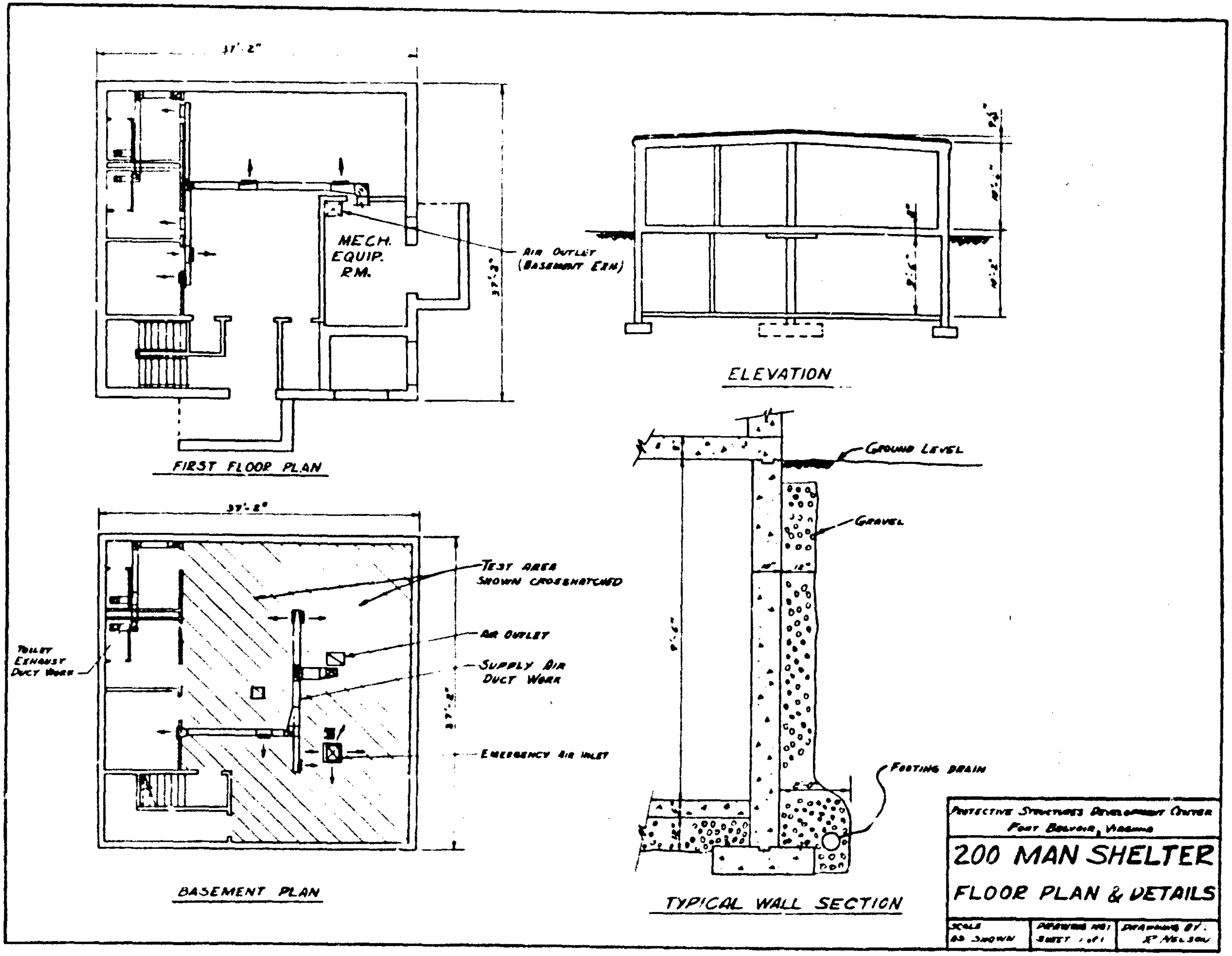

37'-2"
MECH. EQUIP. RM.
AIR OUTLET (BASEMENT EXH)
FIRST FLOOR PLAN
ELEVATION
GROUND LEVEL
GRAVEL
FOOTING DRAIN
TYPICAL WALL SECTION
TOILET EXHAUST DUCT WORK
TEST AREA SHOWN CROSSHATCHED
AIR OUTLET
SUPPLY AIR DUCT WORK
EMERGENCY AIR INLET
BASEMENT PLAN
PROTECTIVE STRUCTURES DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA
200 MAN SHELTER
FLOOR PLAN & DETAILS
SCALE AS SHOWN
DRAWING NO: SHEET 1 of 1
DRAWING BY:

FIGURE No 2

in Figure No. 2. This is a loading ratio of approximately 10 square feet of floor area per person which is in accordance with current OCD minimum requirements.[3] The shelter was instrumented to record the data necessary to determine effective temperatures and ventilation rates.

Heat Load

8. Individual simulated occupants (SIMOCS) were installed in the test area by a research team from the University of Florida. Heat and moisture emitted from these "occupants" were carefully controlled to simulate a total sensible and latent heat output of 400 BTU per hour per person, equivalent to the heat given off by an average adult at rest.[1] Figures 3 and 4 show the simulated occupants in place as well as the water and power metering devices. Figure 5 is a close-up of the occupants.

9. Although the rated capacity of the basement shelter was 100 occupants, the actual number of simulated occupants installed was only 98. However, this reduced number of occupants was operated at slightly increased sensible and latent heat rates to produce the equivalent heat output of 100 occupants.

Ventilating Air

10. The trailer shown in Figure 6 contains an air conditioning plant capable of delivering conditioned air to shelters simulating the diurnal and seasonal variations in outdoor air temperature and humidity conditions which prevail in various areas of the United States. Note the flexible supply and return air ducts between the trailer and the shelter. Conditioned air simulating typical hot summer weather in the Washington, D.C. area was supplied from the trailer at various rates during the course of the test to determine the air quantity required to maintain an internal condition of 85 deg effective temperature or less. The typical design day or the diurnal variations in the psychometric conditions of the air supplied to the shelter is indicated in Figure 7. This design day, developed by Professor Gonzalez of the University of Florida, is based on records of 5-year averages obtained from the weather station at U.S. Army Davison Air Field at Fort Belvoir, Virginia. It represents a 1% day, i.e. the dry bulb and wet bulb temperatures shown will not be exceeded more than 1% of the time.

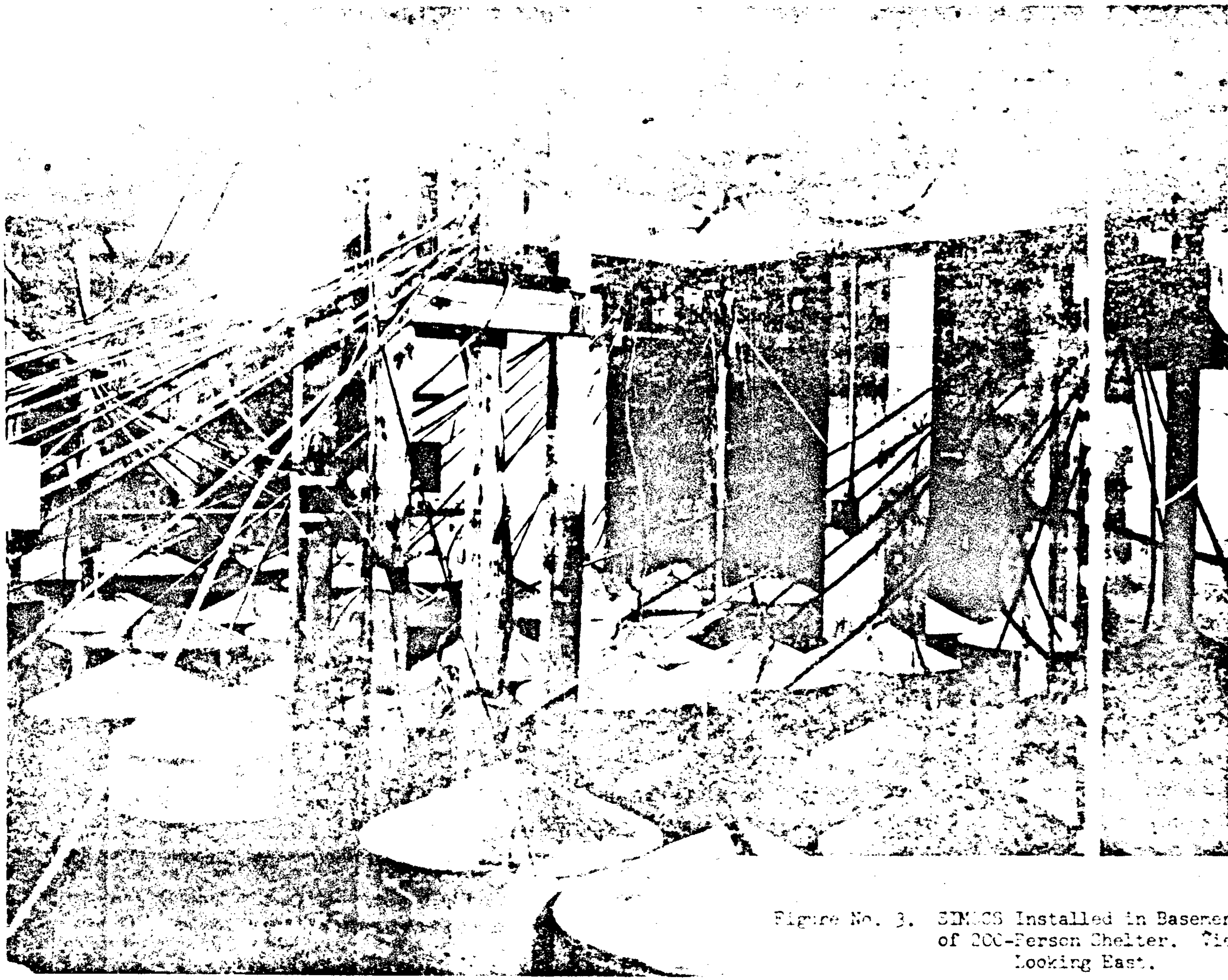


Figure No. 3. SIMCCS Installed in Basement of 200-Person Shelter. View Looking East.

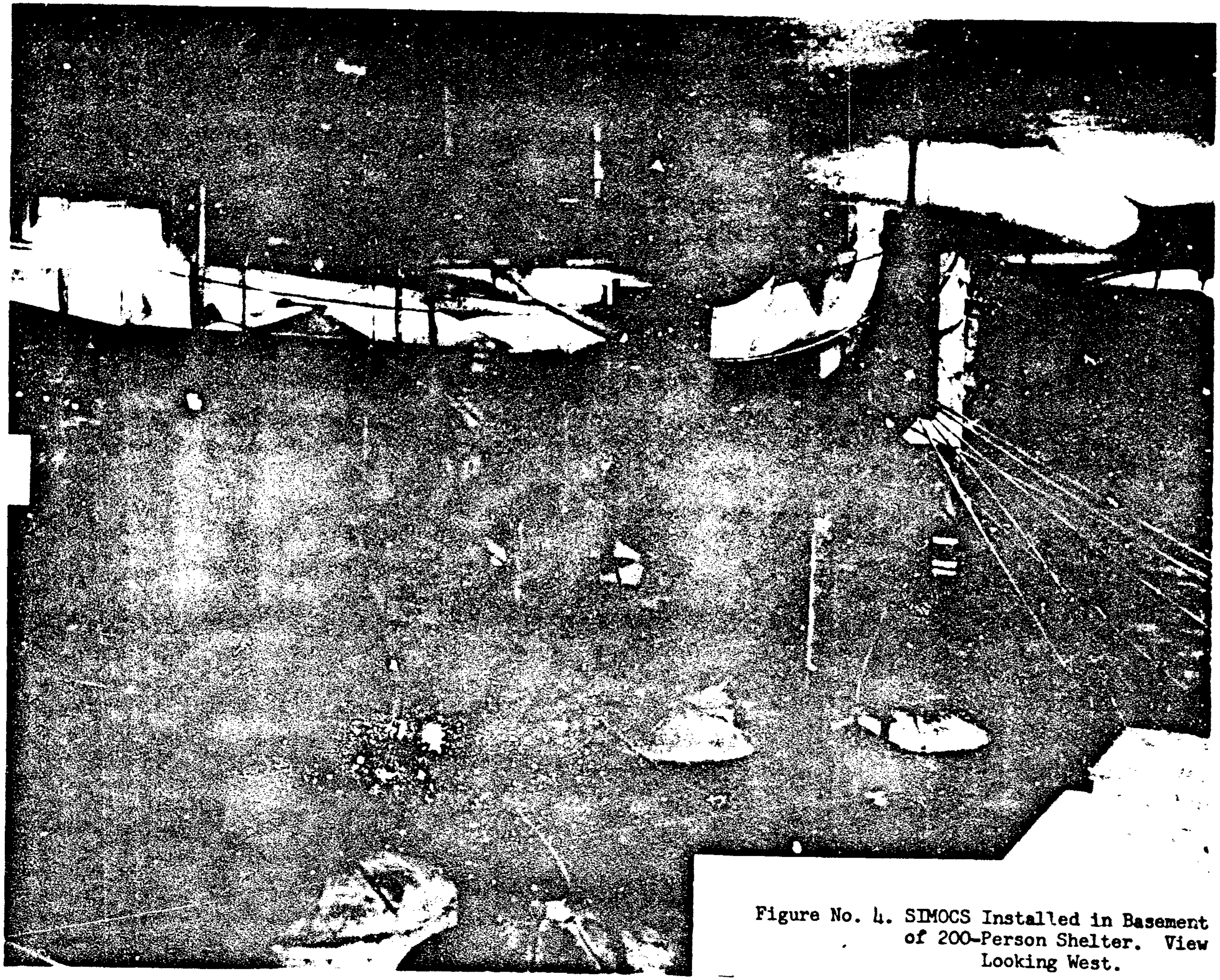


Figure No. 4. SIMOCS Installed in Basement of 200-Person Shelter. View Looking West.

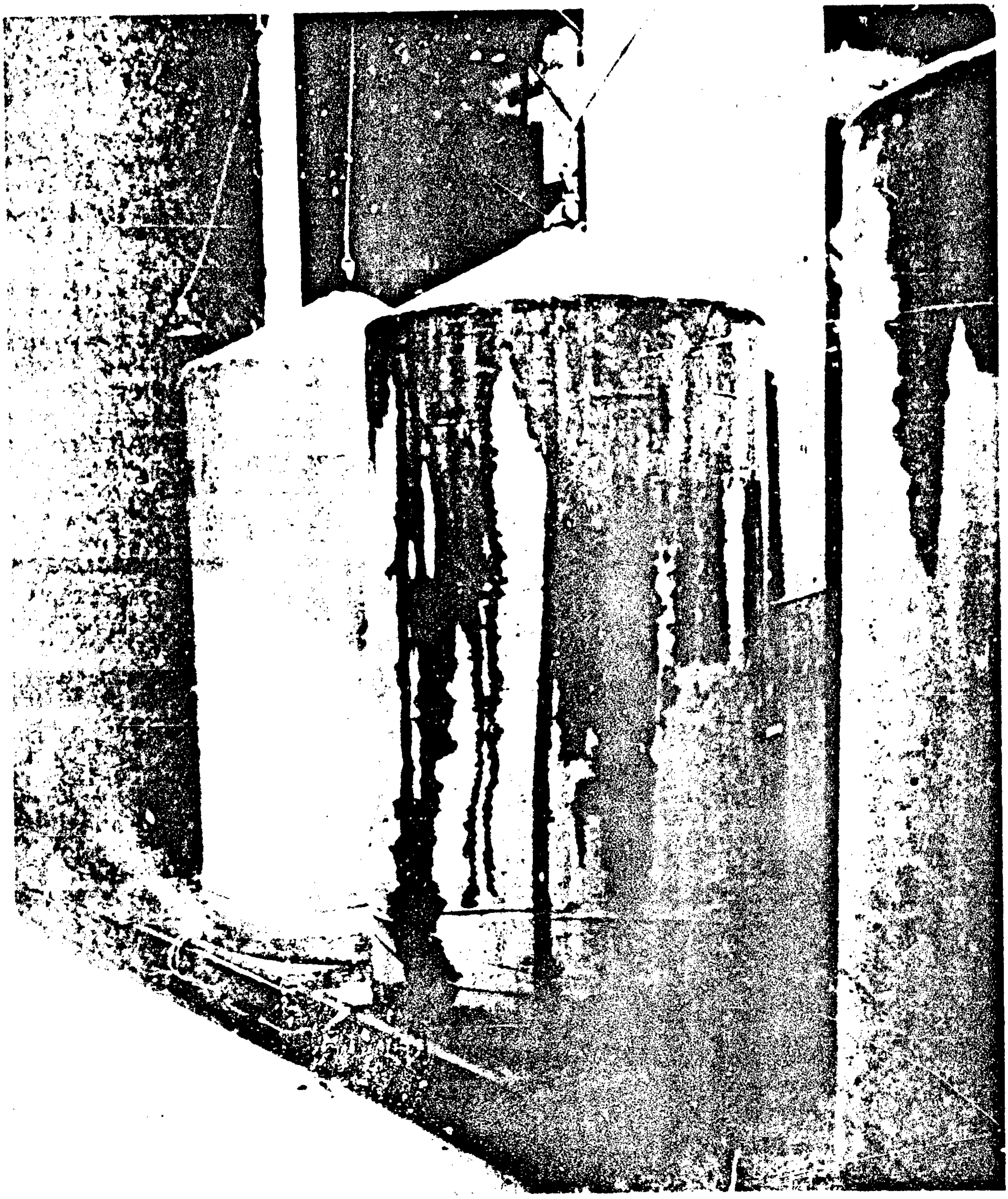


Figure No. 5. Close-up of SIMOCS.

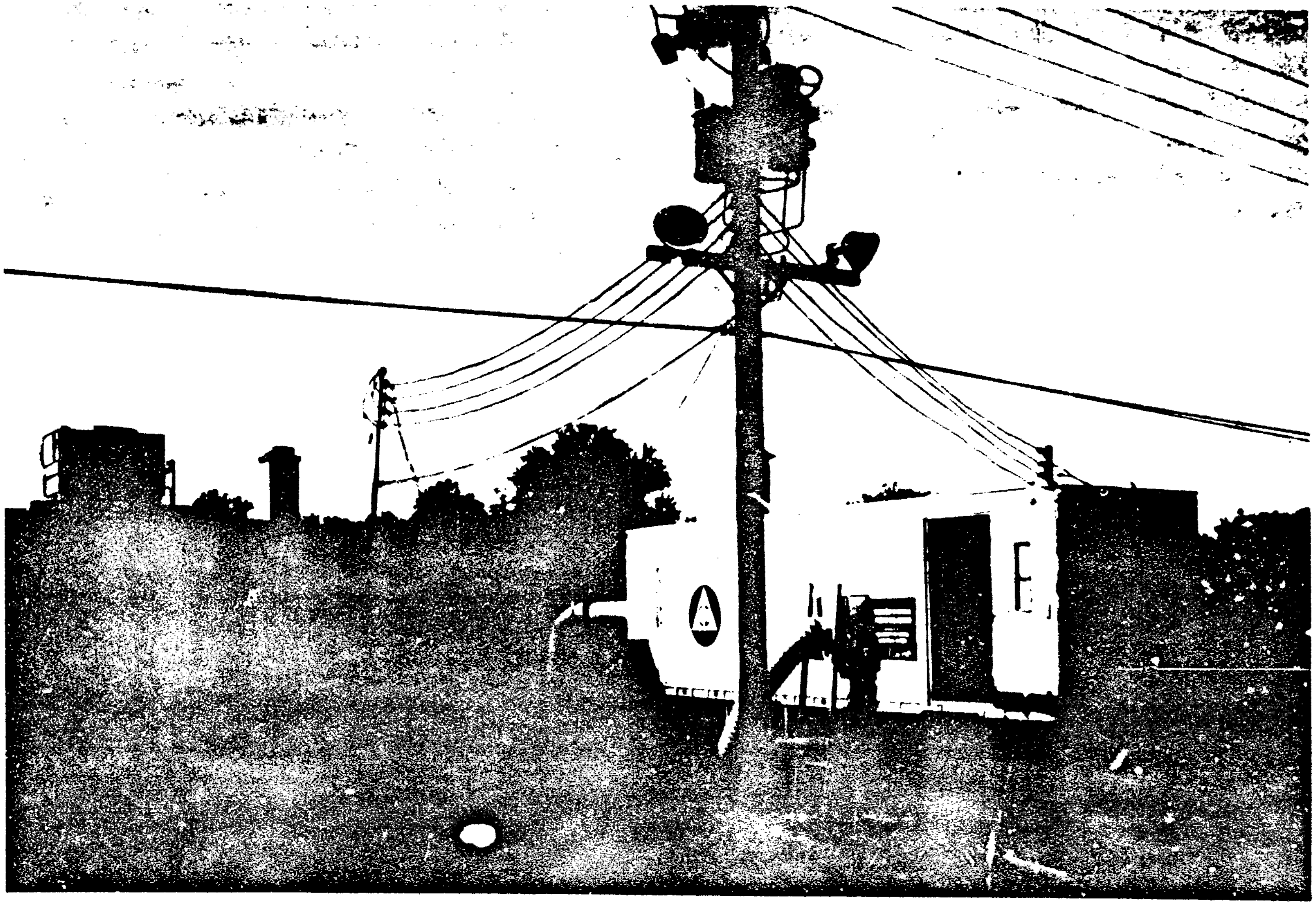
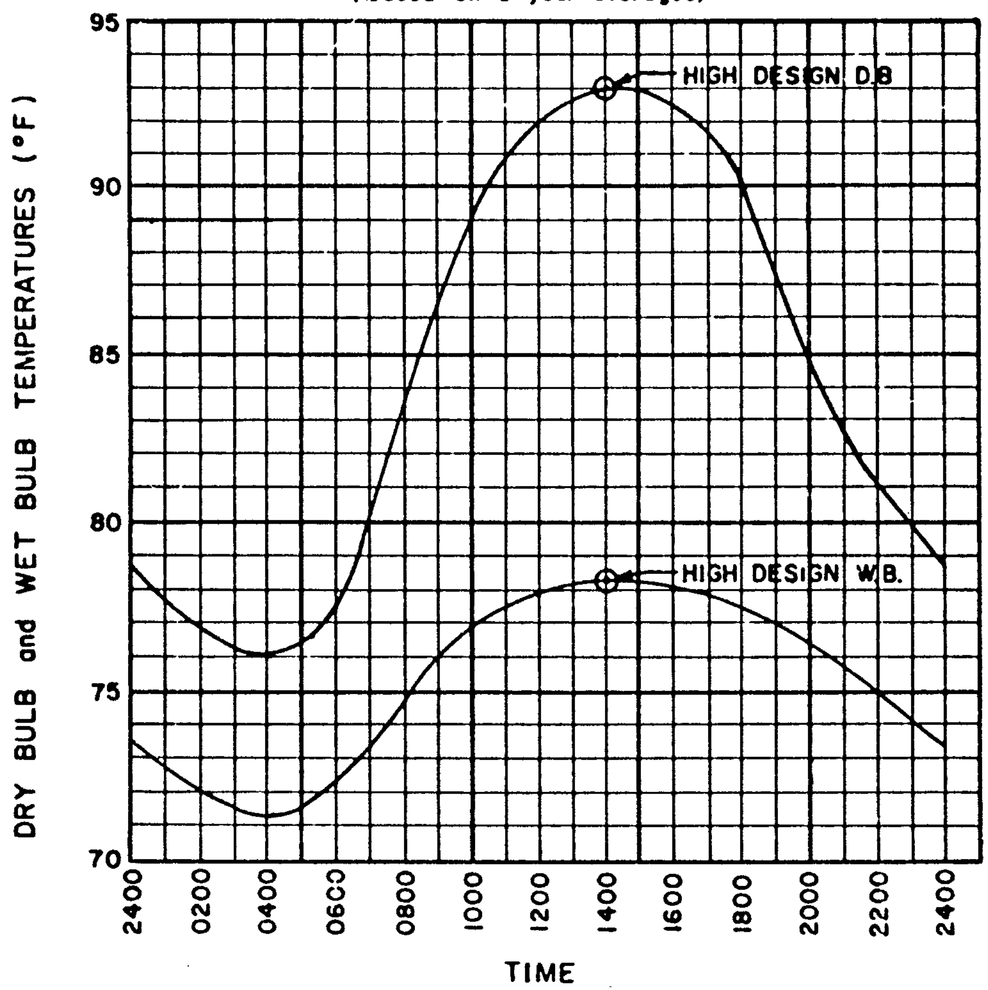


Figure No. 6. The Equipment Trailer Utilized by the University of Florida Personnel to Supply Air of Controlled Conditions to the Shelter and Data Recording.

DIURNAL VARIATION IN TEMPERATURE

FORT BELVOIR, VIRGINIA

(Based on 5 year averages)



1% DESIGN DAY — SHELTER SUPPLY AIR CONDITIONS

FIG. NO. 7

11. During the University of Florida tests the air flow rates varied from 3 to 27 cfm per person. At the start of the tests 3 cfm per person was supplied. As this proved inadequate to maintain an effective temperature of 85 deg or less in the shelter, the air flow rate was subsequently increased to 6, 9, 18 and finally 27 cfm per person. At the end of the test the air flow rate was reduced back to 3 cfm per person to observe the effect of this minimum ventilation rate on the environmental conditions in the occupied shelter during hot summer weather.

12. Since only the basement portion of the shelter was used in the tests, the dry bulb temperature on the first floor was maintained approximately at the same level as in the basement to prevent or minimize heat loss through the concrete floor separating the two areas. The normal building heating system was used for this purpose augmented by electrical heating devices placed on the concrete floor.

Data Recording

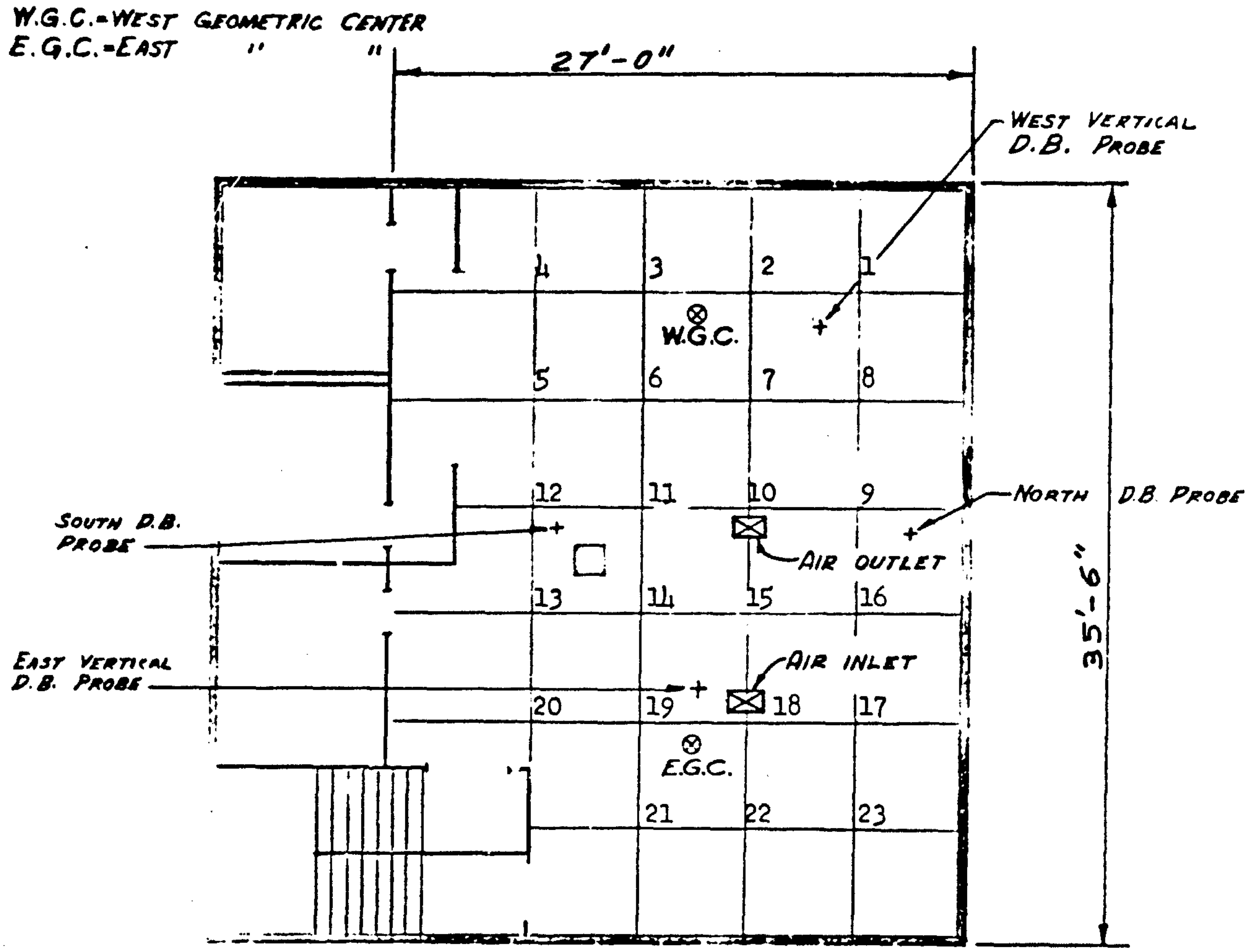
Temperature Data

13. In order to obtain a representative indication of shelter air temperatures at the various test air delivery rates it was decided to establish an imaginary grid for the purpose of fixing locations of shelter temperature measurements. The grid was established in a horizontal plane approximately 4' above the shelter floor. Twenty-three points were recorded at approximately 5-foot intervals as shown in Figure No. 8, "Plan of Effective Temperature Grid". The dry bulb and wet bulb temperatures were measured by means of the psychrometer shown in Figure No. 9 and the effective temperatures were determined at the grid locations using the chart in the 1961 American Society of Heating, Refrigerating and Air Conditioning Engineers Guide and Data Book,[1] Chapter 8, Figure 9. The temperature and ventilation air flow data collected during the tests can be found on the data sheets in Appendix A. The calculated effective temperatures at all points in the grid as well as the average effective temperatures in the shelter are also indicated on these data sheets. The effective temperature grids are plotted on the data sheets contained in Appendix B.

14. The dry bulb and wet bulb temperatures of the supply air, exhaust air and at the east and west geometric centers in the shelter were recorded simultaneously with the grid temperatures. The locations of the east and west geometric centers are indicated on Figure No. 8.

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER — P.S.D.C.



Location Diagram of Temperature Measuring Points.

Figure No. 8

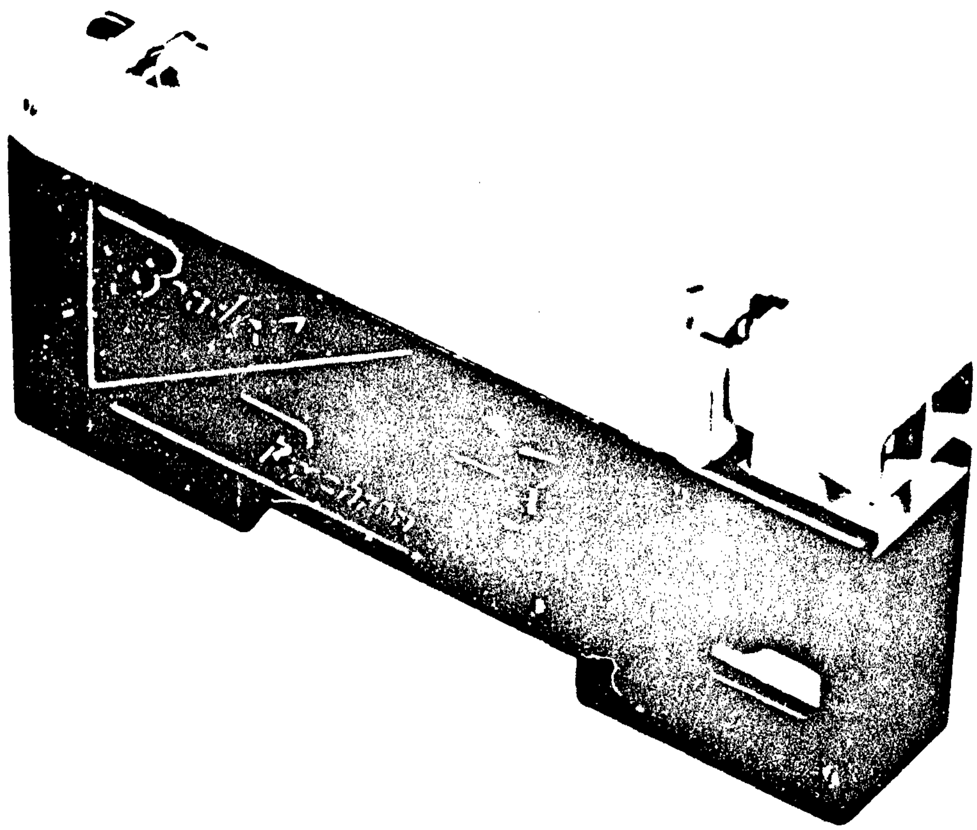


Figure 9 - Battery driven psychrometer. Used to determine the dry bulb and wet bulb temperatures in the shelter. It consists of a dry bulb and wet bulb thermometer and a motor driven fan which circulates air at the proper velocity across both thermometer bulbs.

15. The vertical dry bulb temperature distribution in the shelter was measured using copper-constantan thermocouples mounted at uniform intervals on two probes; one on the east side and one on the west side of the shelter (see Figure No. 8). Temperatures were measured at the 1 inch and 1, 2, 4, 6 and 8 foot levels above the floor on both probes. In addition, the dry bulb temperatures at the 4-foot level at the south end and north end of the shelter were measured. The temperatures were recorded on automatic recording potentiometers located in the mobile equipment trailer (see Figure No. 6).

16. Throughout the tests at least one set of dry bulb and wet bulb readings were obtained for each of the various ventilation air flow rates. These readings were taken at regular intervals following the established grid pattern. The influence of supply air quantities on temperature stratification within the shelter was observed.

Ventilation Air Data

17. The total duration of the tests on this shelter were from 1645 hours, 21 September 1963, to 1640 hours, 11 October 1963. During the entire test period except for the last $25\frac{1}{2}$ hours the ventilation air was introduced into the shelter through a single opening in the ceiling. The existing emergency air inlet in the basement ceiling was used for this purpose. Figure 10 shows the details of this opening complete with a baffleplate. A grid of the effective temperature was plotted from the recorded data to indicate the general pattern of temperature distribution when cooling air is introduced at a single point (see data sheets in Appendix B).

18. The quantity of air supplied to the shelter was determined by means of a vane type anemometer reading air velocities directly in feet per minute (fpm). An eight to twelve point traverse was made in the supply air duct from the trailer using an accessory probe registering velocity pressure (see Figure 11).

19. To observe the effectiveness of duct work to distribute air the dry bulb, wet bulb and effective temperatures were observed while delivering the ventilation air through the existing duct work in the shelter. This was done during the last $25\frac{1}{2}$ hour period of the tests. The minimum ventilation rate of 3 cfm per person was used and measurements were made of air temperatures utilizing the same grid pattern as was used with single point air delivery. An indication of the effectiveness of the duct work in providing better distribution of ventilation air was obtained by comparing the two sets of recorded

temperatures for the two types of distribution systems described above. Note that the simulated occupants are evenly distributed in the test area so that the heat gain per square foot in the shelter is nearly uniform.

20. As described previously, the vertical dry bulb temperature distribution in the shelter was measured simultaneously with the grid pattern temperatures at the 1 inch and 1, 2, 4, 6 and 8 foot levels above the shelter floor in two locations in the shelter (ease side and west side). Similar readings were taken at the 4-foot level on the north and south sides.

21. For both systems of air distribution, single point and duct work, the existing emergency air outlet opening in the ceiling was used as the exhaust outlet for the ventilation air (see Figures 2 and 8).

22. The amount of air delivered from the various registers when the duct system was used was determined using the vane type anemometer. Average air velocity readings were obtained directly in units of feet per minute. By measuring the free area of the registers the air quantities were readily calculated. This data is shown in Appendix C.

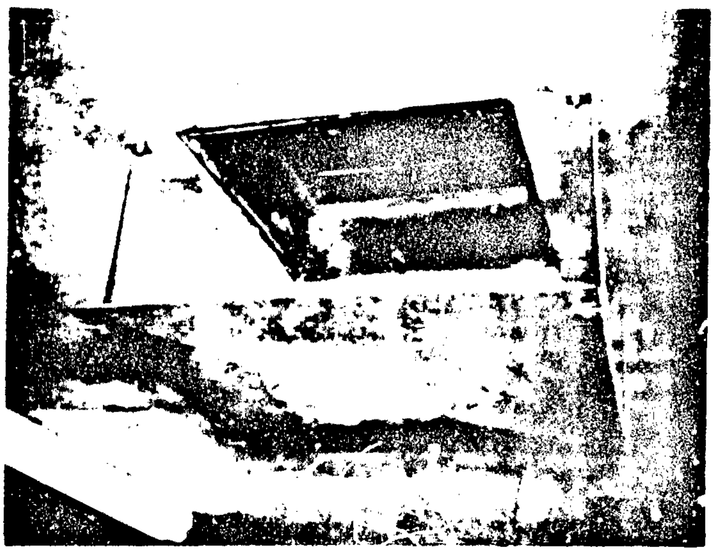


Figure No. 10. Air Inlet Opening in Basement Ceiling.

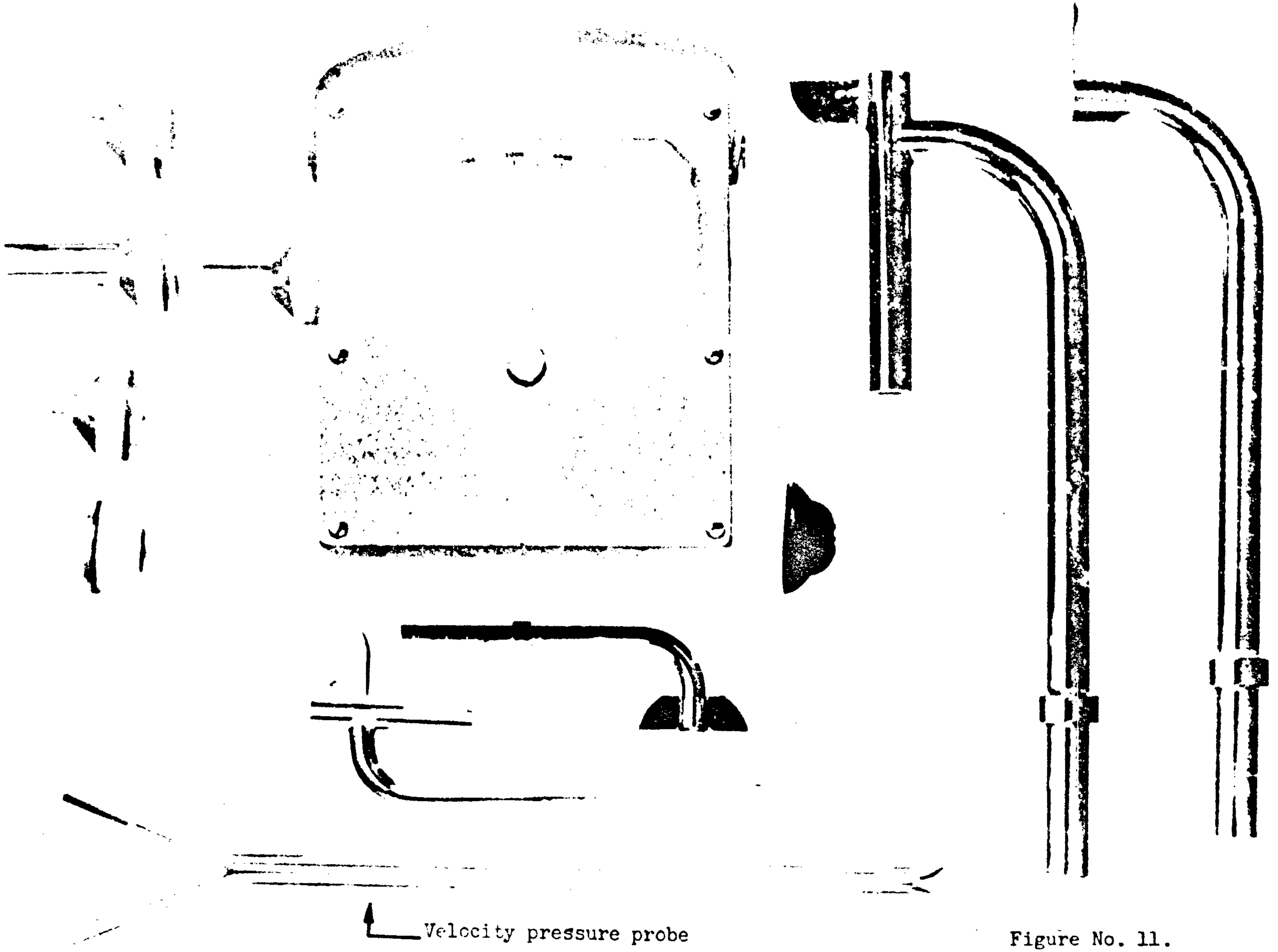


Figure No. 11.

Vane Type Anemometer with Accessories.

SECTION 3: DISCUSSION

Effect of Low Ventilation Rate

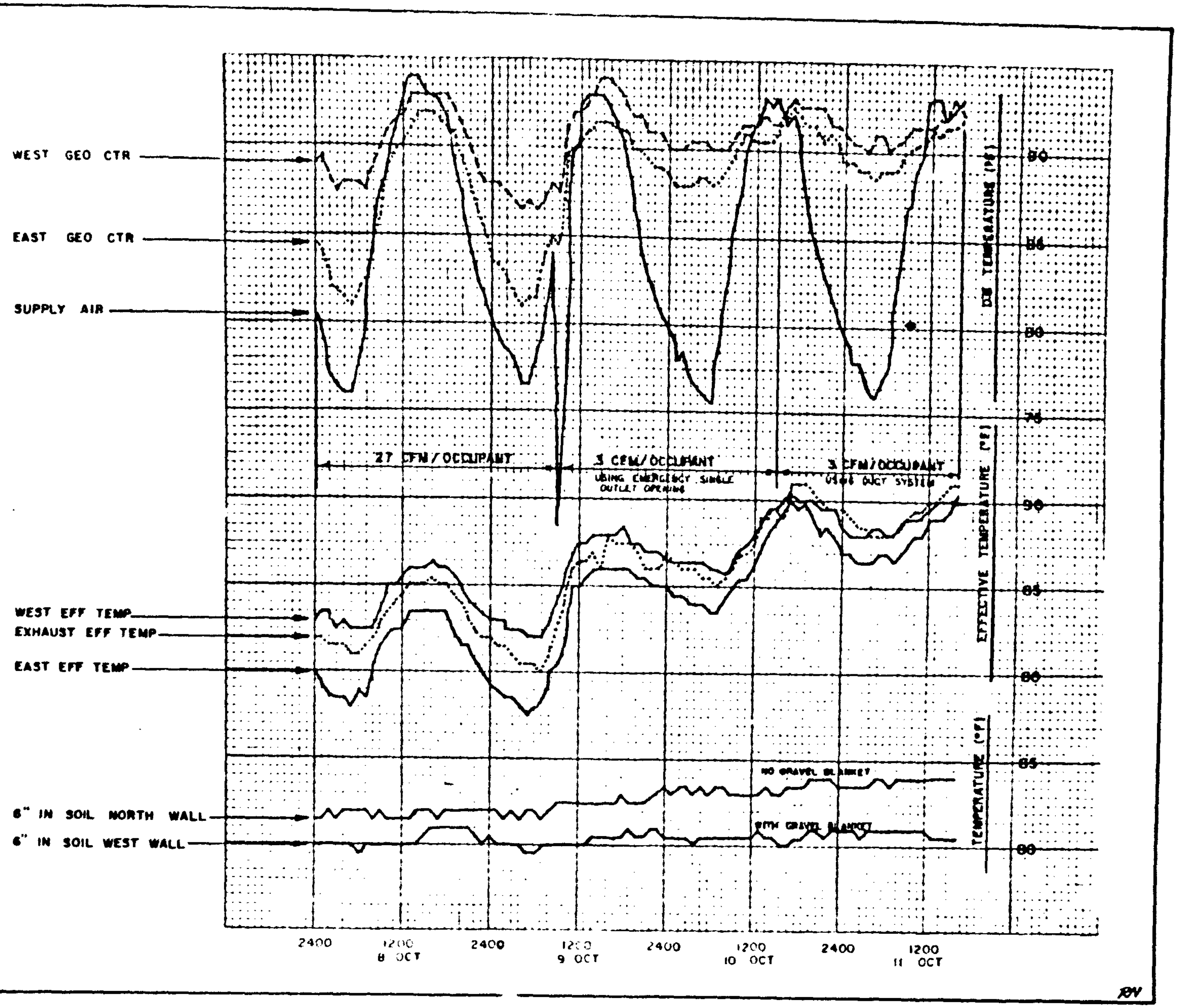
23. The curves shown in Figure 12 were recorded by University of Florida personnel and indicate the relationship between the supply air and the shelter conditions. The curves are plotted beginning at 0100 hours 8 October 1963 to show the conditions which existed immediately before the PSDC portion of the tests were started. Note that the dry bulb, wet bulb, and effective temperatures within the shelter cycled in direct relationship with the diurnal variations in the ventilation air supplied.

24. The curves show that during the PSDC phase of the test, i.e. when ventilation air was supplied at the minimum rate of 3 cfm per person, using both methods of air distribution, the dry bulb temperatures on the west side were consistently between 90 and 95°F and only slightly lower on the east side. At these high temperatures, sensible heat loss by the human body is practically zero and human beings are almost entirely dependent upon evaporative losses for dissipation of metabolic heat. For the purpose of this report it is assumed that an effective temperature of 85 deg is the upper limit of prolonged exposure for healthy humans, prior to onset of heat exhaustion.

25. The curves in Figure 12 show that practically at all times during the PSDC phase of the tests when the minimum ventilation rate of 3 cfm was supplied, the shelter effective temperatures exceeded 85 deg. After $55\frac{1}{2}$ hours of operation with this low air supply rate the effective temperature of the exhaust air reached 91 deg. During the previous 24 hours the minimum effective temperature observed in the shelter was 86.5 deg. The tests were terminated when the shelter effective temperature continued to increase beyond the level where heat exhaustion is possible for healthy acclimatized persons.

Temperature Differences Within the Shelter

26. Figure 13 illustrates graphically the relationship between the effective temperatures of the supply air, the exhaust air, and the average shelter effective temperature existing at the time grid temperatures were taken. Note that the average shelter effective temperature exceeds the ventilation air effective temperature at all times.



WEST GEO CTR
EAST GEO CTR
SUPPLY AIR
WEST EFF TEMP
EXHAUST EFF TEMP
EAST EFF TEMP
6" IN SOIL NORTH WALL
6" IN SOIL WEST WALL
27 CFM/OCCUPANT
3 CFM/OCCUPANT
USING EMERGENCY SINGLE OUTLET OPENING
3 CFM/OCCUPANT
USING DUCT SYSTEM
NO GRAVEL BLANKET
WITH GRAVEL BLANKET
DB TEMPERATURE (°F)
EFFECTIVE TEMPERATURE (°F)
TEMPERATURE (°F)
90
85
80
75
90
85
80
85
80
2400
1200
8 OCT
2400
1200
9 OCT
2400
1200
10 OCT
2400
1200
11 OCT

FIG NO 12

27. From page 3 of the data sheets in Appendix A, Appendix B and Table I it is found that a difference as high as 4 deg in the effective temperature existed between the west side of the shelter and the east side. This maximum difference occurred with a relatively large air flow of 18 cfm/occupant. The lower temperatures prevailed on the east side where the ventilation air was introduced through the existing emergency air inlet opening in the ceiling. It is significant to note that the air quantity supplied to the shelter throughout the tests had no marked influence on the effective temperature stratification as observed during the single point air delivery phase of the tests. Even when the maximum rate of 27 cfm per occupant was supplied to the shelter a difference of 2 deg was observed between the two sides in the shelter. However, it is noted that the difference in effective temperatures between the various areas in the shelter was reduced to 1-2 deg when supplying air through the duct work. This was accomplished during the last phase of the test using the minimum air flow rate of 3 cfm per person. It is reasonable to assume that a greater amount of air supplied through the duct work would tend to decrease this differential still further due to increased turbulence and greater entrainment of room air with the supply air. The degree of decrease should be verified by tests. Table I illustrates the temperature differences observed during the various phases of the tests.

28. An indication of the effectiveness of the duct work in providing better distribution of ventilation air may be noted by comparing the two sets of recorded temperatures for the two systems of distribution. This is based on the theory that the temperature distribution is a direct indication of the effectiveness of the duct work in distributing the air throughout the shelter. In other words, if the temperatures are found to be uniform throughout the shelter, so is the air distribution.

29. Table I illustrates the approximate differences in effective temperatures between the east and west sides of the shelter as observed during the tests at various rates of air flow. A difference of $1\frac{1}{2}$ to 2 deg was observed with a ventilation rate of 6 cfm per occupant and it gradually increased to 3 to 4 deg as observed with an air flow of 18 cfm per occupant. When the air flow was finally increased to 27 cfm per occupant the difference in the effective temperature was decreased $1\frac{1}{2}$ to 2 deg. The steady increase in the temperature difference using air flow rates from 6 to 9 to 18 cfm per occupant is attributed to the fact that insufficient turbulence or mixing was present to equalize the temperatures in the shelter. Finally when the air flow was increased to 27 cfm per occupant the turbulence was significant and nearly equalized the recorded temperatures. When the air flow subsequently was reduced to the minimum rate of 3 cfm per occupant the temperature differential steadily increased to a value

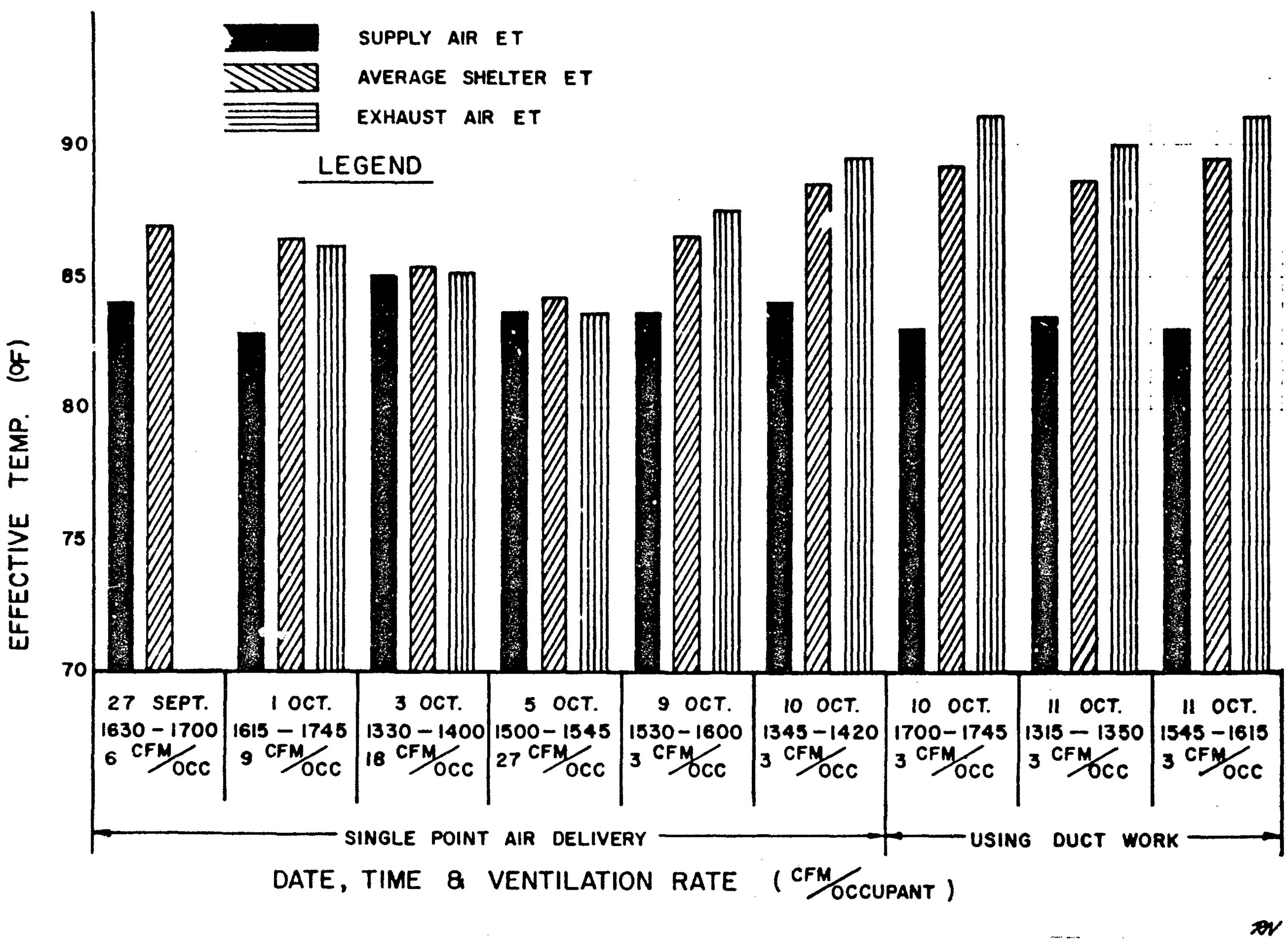

SUPPLY AIR ET
AVERAGE SHELTER ET
EXHAUST AIR ET
LEGEND
90
85
80
75
70
EFFECTIVE TEMP. (°F)
27 SEPT. 1630 - 1700 6 CFM/OCC
1 OCT. 1615 — 1745 9 CFM/OCC
3 OCT. 1330 — 1400 18 CFM/OCC
5 OCT. 1500 — 1545 27 CFM/OCC
9 OCT. 1530 — 1600 3 CFM/OCC
10 OCT. 1345 — 1420 3 CFM/OCC
10 OCT. 1700 — 1745 3 CFM/OCC
11 OCT. 1315 — 1350 3 CFM/OCC
11 OCT. 1545 — 1615 3 CFM/OCC
SINGLE POINT AIR DELIVERY
USING DUCT WORK
DATE, TIME & VENTILATION RATE (CFM/OCCUPANT)

Figure No. 13

TABLE I

TEMPERATURE DIFFERENCES WITHIN THE SHELTER

DATE	TIME	AIR FLOW RATE CFM/OCCUPANT	METHOD OF AIR DELIVERY	APPROX. DIFFERENCE (ΔT) IN EFFECTIVE TEMPERATURE BETWEEN EAST & WEST SIDE OF SHELTER	REPRESENTATIVE AVG. ΔT IN DRY BULB TEMP. BETWEEN E. & W. SIDE OF SHELTER	REPRESENTATIVE AVG. ΔT IN WET BULB TEMP. BETWEEN E. & W. SIDE OF SHELTER	MAXIMUM ΔT IN WET BULB TEMP. BETWEEN E. & W. SIDES	VERTICAL ΔT IN DB TEMPERATURES	
								E. SIDE	W. SIDE
27 Sept.	1630-1700	6	Single Opening	1 1/2 - 2	1 - 1 3/4	3 1/2	4	1	1
1 Oct.	1730-1815	9	" "	2 - 3	0 - 1 1/2	5	7	1	1 1/2
3 Oct.	1330-1400	18	" "	3 - 4	0 - 1/2	5 1/2	7	1	1 1/2
5 Oct.	1500-1545	27	" "	1 1/2 - 2	0	3 1/2	5	1	1 1/2
9 Oct.	1530-1600	3	" "	2 - 2 1/2	1 1/2	3 1/2	3 1/2	1	2
10 Oct.	1345-1420	3	" "	2 - 3 1/2	1 1/2	4	4 3/4	1/2	1 1/2
10 Oct.	1700-1745	3	Ductwork	1/2 - 1 1/2	1/2	2 1/2	2 1/2	1	1 1/2
11 Oct.	1315-1350	3	"	1 - 2	1	2 1/2	3 1/4	1/2	1 1/2
11 Oct.	1545-1615	3	"	1 - 2	1	2 1/2	3 1/4	1/2	1

of approximately $3\frac{1}{2}$ deg. Finally when the ventilation air was delivered through the distribution duct work (still at the minimum rate of 3 cfm per occupant), a difference of 1 to 2 deg was observed in the effective temperatures in the shelter between the east and west sides. This may seem greater than expected, however, it should be noted that air quantities delivered through registers Nos. 3 and 4 on the west side were low compared to the air quantities delivered through registers Nos. 1 and 2 on the east side (see Appendix C). This imbalance existed primarily because register No. 5, located outside the test area, was blocked during the duct work phase of the tests. Differences in effective temperatures between the east and west sides of the shelter were mainly due to differences in wet bulb temperatures which varied from 3 to 7°F. The dry bulb temperatures generally varied only 1 to $1\frac{1}{2}$°F between the two sides. This is indicated on the data sheets, pages 1 to 9, Appendix A and Table I.

Effect of SIMOCS

30. It should be pointed out that the simulated occupants were sedentary. In an actual shelter situation with human occupants there would be an inclination on the part of the occupants to move toward the cooler areas in the shelter. Thus, heat emittance in the warm areas would be reduced due to decreased population and a corresponding gain would occur in the cooler areas tending to equalize the shelter temperatures.

Air Distribution and Mixing

31. The bar graph shown in Figure 13 illustrates the relationship between effective temperatures of the supply air, the exhaust air, and the average effective temperature within the shelter. The graph indicates that whenever the average effective temperatures within the shelter exceeded the exhaust air effective temperature, the ventilation air flow rate was insufficient to cause good mixing of the air within the shelter, or that the air supplied short-circuited between the inlet opening and the exhaust opening. Note that for the ventilation air flow of 18 cfm and 27 cfm per occupant the effective temperature of the inlet air is approximately equal to the effective temperature of the exhaust air. This would indicate a short circuit. On the 9th and 10th of October when the air flow rate was reduced to 3 cfm per occupant and still using single point air delivery the exhaust air effective temperature is considerably above the supply air effective temperature indicating that the air

has had sufficient time to pick up more of the moisture load. However, the effective temperatures within the shelter, of course, were much higher than when the greater air flow rates were used. Also note that during this period the average shelter effective temperature is consistently lower than the exhaust air effective temperature. Unfortunately, the data is not altogether conclusive. It is assumed that further studies of air velocities and velocity patterns in shelters of various configurations may throw more light on this particular problem. When the air was delivered through the duct work, however, the exhaust air effective temperature exceeded at all times the average shelter effective temperature and was considerably higher than the supply air effective temperature.

32. The center portion of the graphs illustrated in Figure 12 shows the effective air temperatures of the east side, the west side and the exhaust air plotted against time. Note that on this graph the vertical distance between the effective temperature curves on the east side and the west side is a direct indication of how well the ventilation air and room air have been mixed. The greater the distance, the poorer the mixing of air within the shelter. When the two effective temperature curves merge together, good mixing is indicated. It is significant to note that when air was supplied through the duct work these curves were close together, indicating that more uniform shelter temperatures existed.

Factors Affecting Heat Transfer

33. A study of the effective temperature grid data sheets reveals that the northeast corner was the coldest area within the shelter throughout the tests. This is partly due to a possible imbalance in the quantity of air delivered and partly because the Mechanical Room on the first floor is located directly above this area. In order to accommodate the flexible supply and return air ducts between the shelter and the equipment trailer, the door to this room had to be open at all times during the tests, thus allowing the outdoor ambient air to cool the floor slab. This was very apparent toward the end of the tests when heavy condensation occurred on the ceiling in the shelter in this area.

34. Another factor which influenced the shelter temperatures in this vicinity was discovered by University of Florida personnel. It was detected that the gravel blanket which surrounds the basement walls of the shelter was not provided along 2/3 of the north wall. Thus, greater heat transfer through the wall to the surrounding soil occurred in this area due to the absence of the insulating gravel blanket. This is indicated by the two lower curves on graph, Figure 12, which show soil temperatures at points 6 inches out from the

north and west shelter walls at a depth of approximately 5 feet from the grade surface. It should be noted that the precipitation was unusually low during the University of Florida tests, and it may well be found that during rainy periods the heat removal through the walls in the areas where the gravel blanket exists may be greater than where the soil is in direct contact with the walls. The gravel would provide for rapid percolation of rain water through the blanket which would carry heat away from the shelter walls.

Vertical Temperature Stratification

35. The vertical dry bulb temperature stratification in the shelter was relatively small, the differences generally not exceeding $1\frac{1}{2}^{\circ}F$ between the 1-foot and 8-foot levels above the floor. On the west side of the shelter the vertical dry bulb temperature variations generally did not exceed 1 to $1\frac{1}{2}^{\circ}F$, the lowest temperatures being observed near the floor and the higher temperatures progressively increasing as the distance above the floor. On the east side, however, a lower dry bulb temperature was frequently observed at the 8-foot level above the floor than at the 1-foot level. This is attributed to the fact that the temperature probe on the east side was located close to the ventilation air inlet in the ceiling. The relatively cool supply air directly affected the thermocouples at the 6-foot and 8-foot levels more than those closer to the floor.

SECTION 4: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

36. With single point air delivery, stratification in this small shelter was considerable, even when supplying relatively large air quantities. This points to the importance of proper air distribution in survival shelters and indicates the need for further studies of air distribution methods within fallout shelters. The variations in air quantities supplied did not have marked influence on the temperature stratification throughout the shelter. This is true at least until the maximum quantity of 2700 cfm was delivered. At this rate turbulence apparently became sufficient to nearly equalize the temperatures within the shelter. The data is not entirely conclusive;

however, it appears that even at this high ventilation rate when delivering air through a single inlet opening there was a significant short circuit of the ventilation air within the shelter.

37. The effectiveness of the duct work was clearly demonstrated, even when supplying the minimum ventilation rate of 3 cfm per occupant. This shows that proper air distribution can readily be accomplished with well designed and properly balanced duct work. At this ventilation rate a difference in effective temperatures between the east and west sides of the shelter was observed to be 1 to 2 deg. It is safe to assume that had the ventilation rate been higher this differential would have been decreased or eliminated entirely. The fact that the air outlet to one room was blanked off causing an imbalance in the duct work tended to allow this differential to occur. This could be eliminated simply by regulating and adjusting the registers.

38. When supplying ventilation air representing a 1% design day at the minimum rate of 3 cfm per occupant the effective temperature within the shelter climbed above 90 deg. It is therefore concluded that the 3 cfm per occupant ventilation rate is inadequate for providing a tolerable thermal environment in occupied underground survival shelters of the configuration tested during hot summer weather in the Washington, D.C. area, based on a 1% design day. This conclusion is valid for other areas with similar climatic and ground conditions. In smaller shelters, such as family shelters, or other shelters with large exposed underground wall, floor or ceiling areas per occupant, the dissipation of heat to these cool boundaries may be sufficient so that a minimum ventilation rate would be adequate. For shelter ventilation purposes, based on providing a "survival" only thermal environment, it may be more reasonable to assume a 5% or even a 10% design day rather than the 1% day used in the tests covered by this report. Further investigation to establish shelter design temperatures throughout the United States are now underway under auspices of the Office of Civil Defense. It should be noted, however, that a 1% summer design temperature is recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers and is in common use by practicing engineers in the design of summer air conditioning systems.

Recommendations

39. It is recommended that further studies of air distribution and air velocity problems within fallout shelters be undertaken with

the objective of obtaining useful engineering data for aid in selection of suitable ventilation systems and equipment to provide satisfactory air distribution in shelters. The ventilation and air distribution system in a survival shelter should be capable of minimizing stratification and dead air pockets and providing ventilation air of uniform quantity and quality to all occupants.

40. Further research should be conducted to determine the upper limits of temperature and humidity conditions which can be tolerated for a required period of time and insure survival of a majority of individuals representing an average cross section of the population. It is known that the environmental tolerance limits will vary from individual to individual and are affected by such factors as state of health, acclimatization and age.

41. A study should be made to determine whether a 1%, 5% or 10% design day should be applicable in design of survival shelters.

LIST OF REFERENCES

1. American Society of Heating, Refrigerating and Air Conditioning Engineers Guide and Data Book, 1961.

2. N. M. Newmark, Design of Openings for Buried Shelters, July 1963, U. S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.

3. Office of Civil Defense, Minimum Technical Requirements for Group (Community) Shelters, Technical Memorandum 61-3, August 1962.

4. Office of Civil Defense, Catalog of Shelter Components, PG 80-10, November 1962.

APPENDIX A

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 27 SEPT 63 TIME: 1630-1700 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 600 * CFM. CFM/OCCUPANT: 6

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	91.0	85.5	87.2
2	91.75	86.0	87.6
3	91.0	86.5	87.7
4	91.0	86.0	87.4
5	91.0	86.0	87.4
6	91.5	85.5	87.3
7	91.0	85.0	87.0
8	90.0	86.0	87.1
9	92.0	85.5	87.5
10	92.5	85.0	87.2
11	92.0	85.5	87.5
12	91.0	85.0	87.0
13	91.0	85.5	87.1
14	91.0	85.0	87.0
15	91.0	84.5	86.6
16	91.0	85.0	87.0
17	92.5	84.0	86.1
18	91.0	83.5	86.0
19	90.5	83.5	85.9
20	91.0	84.0	86.2
21	90.0	82.5	85.1
22	91.0	82.75	85.6
23	90.0	82.5	85.1
AV. EFF. TEMP.			86.8

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		91.6	79.0	84.0
EXHAUST AIR CONDITION				
EAST GEOMETRIC CENTER		90.0	82.0	85.0
WEST GEOMETRIC CENTER		90.5	86.0	
VERTICAL	DB 1" ABOVE FLOOR	88.0		
TEMP.	1' " "	90.5		
PROBE	2' " "	90.5		
EAST	4' " "	90.0		
	6' " "	89.5		
	8' " "	89.5		
VERTICAL	1" ABOVE FLOOR	87.0		
TEMP.	1' " "	89.0		
PROBE	2' " "	89.5		
WEST	4' " "	90.0		
	6' " "	90.0		
	8' " "	90.0		
NORTH DB, 4' ABOVE FLOOR		92.0		
SOUTH DB, 4' ABOVE FLOOR		90.0		

REMARKS

* Changed from 300 cfm at approx. 1545 hrs.

SINGLE POINT AIR DELIVE

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 1 OCT '63 TIME: 1615-1745 OBSERVER: ZIEGLER

TOTAL VENTILATION RATE: 893 CFM. CFM/OCCUPANT: 8.93

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	91.0	87.5	86.6
2	91.5	86.5	88.0
3	91.75	87.0	88.2
4	91.0	87.0	88.0
5	91.0	86.75	88.0
6	91.0	85.0	86.9
7	91.0	84.5	86.5
8	91.5	84.25	86.7
9	92.0	84.0	86.5
10	92.5	83.75	86.6
11	91.75	83.5	[illegible]
12	91.5	86.0	87.6
13	91.25	84.25	86.4
14	91.25	84.25	86.6
15	91.0	82.0	85.1
16	91.5	83.0	85.9
17	91.0	82.0	85.1
18	[illegible]	82.5	85.1
19	[illegible]	83.0	85.9
20	[illegible]	87.0	86.2
21	91.0	83.5	86.0
22	90.5	81.5	85.0
23	89.75	80.0	83.6
AV. EFF. TEMP.			86.9

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		90.0	78.0	82.8
EXHAUST AIR CONDITION		91.5	83.5	86.1
EAST GEOMETRIC CENTER				
WEST GEOMETRIC CENTER				
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	89.0		
	1' " "	92.0		
	2' " "	92.0		
	4' " "	91.5		
	6' " "	91.0		
	8' " "	91.0		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	90.0		
	1' " "	92.0		
	2' " "	92.5		
	4' " "	91.5		
	6' " "	91.0		
	8' " "	91.0		
NORTH DB, 4' ABOVE FLOOR		91.0		
SOUTH DB, 4' ABOVE FLOOR		91.0		

REMARKS

SINGLE POINT AIR DELIVERY

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 3 OCT '63 TIME: 1330 - 1400 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 1800 CFM. CFM/OCCUPANT: 18

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	90.5	83.75	86.0
2	90.5	82.75	85.5
3	91.0	85.5	87.2
4	90.5	85.75	87.2
5	90.5	85.0	86.8
6	91.0	84.0	86.2
7	90.5	83.5	86.0
8	90.75	82.75	85.5
9	90.5	81.5	84.9
10	91.0	82.5	85.5
11	91.0	84.0	86.3
12	91.0	84.0	86.3
13	90.5	82.5	85.1
14	90.5	83.0	85.6
15	91.0	83.0	85.8
16	90.5	82.0	85.0
17	89.5	86.0	83.6
18	89.5	80.25	83.8
19	91.0	82.5	85.5
20	90.5	82.0	85.0
21	90.25	80.5	84.2
22	90.0	80.25	84.0
23	89.5	78.75	83.0
AVG. E.T. TEMP.			85.4

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		93.5	80.0	85.0
EXHAUST AIR CONDITION		91.0	82.0	85.1
EAST GEOMETRIC CENTER				
WEST GEOMETRIC CENTER				
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	89.0		
	1' " "	91.5		
	2' " "	91.5		
	4' " "	91.0		
	6' " "	90.5		
	8' " "	91.0		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	88.5		
	1' " "	90.0		
	2' " "	90.5		
	4' " "	91.0		
	6' " "	91.0		
	8' " "	91.5		
NORTH DB, 4' ABOVE FLOOR		91.0		
SOUTH DB, 4' ABOVE FLOOR		91.0		

REMARKS

SINGLE POINT AIR DELIVERY

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 5 OCT '63 TIME: 1500-1545 OBSERVER: SVACRI

TOTAL VENTILATION RATE: 2700 CFM. CFM/OCCUPANT: 27

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	89.5	79.5	83.4
2	90.5	81.25	84.9
3	90.0	82.5	85.1
4	89.5	83.0	85.2
5	90.0	82.25	85.0
6	90.25	82.0	85.0
7	90.5	81.25	84.7
8	89.5	79.5	83.3
9	91.0	80.5	84.3
10	91.0	81.5	85.0
11	90.5	81.5	84.7
12	90.0	81.25	84.7
13	90.5	80.0	84.0
14	90.5	81.5	84.8
15	90.5	79.75	84.0
16	90.5	80.75	84.5
17	90.5	79.25	83.6
18	90.5	79.0	83.4
19	91.5	79.5	84.0
20	90.5	79.0	83.4
21	90.75	78.25	83.2
22	90.25	78.0	82.9
23	89.25	77.75	82.3
AV. EFF TEMP.			84.2

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		93.0	77.5	83.6
EXHAUST AIR CONDITION		90.5	79.5	83.7
EAST GEOMETRIC CENTER				
WEST GEOMETRIC CENTER				
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	90.0		
	1' " "	92.0		
	2' " "	92.0		
	4' " "	91.0		
	6' " "	91.0		
	8' " "	91.0		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	89.5		
	1' " "	90.0		
	2' " "	90.0		
	4' " "	90.0		
	6' " "	90.0		
	8' " "	90.5		
NORTH DB, 4' ABOVE FLOOR		90.5		
SOUTH DB, 4' ABOVE FLOOR		91.0		

REMARKS

SINGLE POINT AIR DELIVERY

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 9 OCT 63 TIME: 1530-1600 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 300 CFM. CFM/OCCUPANT: 3

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	92.5	84.0	86.8
2	92.5	83.5	86.5
3	92.0	85.5	87.5
4	91.75	85.5	87.4
5	91.5	85.0	87.0
6	92.5	85.5	87.7
7	92.5	85.0	87.3
8	92.5	84.0	87.0
9	92.75	84.0	87.0
10	92.5	84.25	87.0
11	92.25	85.25	87.5
12	91.25	84.5	86.8
13	91.25	84.5	86.8
14	91.75	84.75	87.0
15	91.75	84.0	86.5
16	92.0	83.5	86.4
17	90.5	82.0	85.0
18	90.75	82.0	85.0
19	91.0	83.25	86.0
20	91.25	84.25	86.6
21	91.5	82.5	85.6
22	91.0	82.0	85.1
23	90.5	82.25	85.1
AVG. EFF. TEMP.			86.5

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		92.5	78.0	83.6
EXHAUST AIR CONDITION		93.0	85.0	87.5
EAST GEOMETRIC CENTER		91.5	83.5	86.1
WEST GEOMETRIC CENTER		94.0	85.0	87.8
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	87.5		
	1' " "	90.5		
	2' " "	91.5		
	4' " "	91.5		
	6' " "	91.5		
	8' " "	91.5		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	90.0		
	1' " "	92.0		
	2' " "	92.5		
	4' " "	93.0		
	6' " "	93.0		
	8' " "	94.0		
NORTH DB, 4' ABOVE FLOOR		92.5		
SOUTH DB, 4' ABOVE FLOOR		91.5		

REMARKS

17 SIMOCS DRY NEAR POINT #4
10 — " — " — #14
(DISTRIBUTOR PUMP TROUBLE)

SINGLE POINT AIR DELIVERY

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 10 OCT '63 TIME: 1345-1420 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 300 CFM. CFM/OCCUPANT: 3

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	91.5	88.25	89.1
2	92.0	88.50	89.5
3	92.5	89.0	89.9
4	92.0	89.0	89.8
5	92.0	89.0	89.8
6	92.5	89.0	89.9
7	92.0	88.75	89.6
8	91.5	88.75	89.5
9	91.75	87.5	88.8
10	93.5	88.0	89.5
11	93.0	87.5	89.0
12	91.5	87.5	88.6
13	91.25	87.5	88.5
14	91.75	87.0	88.2
15	91.5	86.75	88.1
16	91.5	87.25	88.5
17	91.0	85.25	87.1
18	90.5	85.25	87.0
19	90.5	85.75	87.2
20	90.75	86.75	87.9
21	90.5	85.75	87.2
22	90.5	84.25	86.2
23	89.75	84.5	86.1
AVG. EFF. TEMP.			88.5

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		92.5	79.0	84.0
EXHAUST AIR CONDITION		92.5	88.5	89.6
EAST GEOMETRIC CENTER		90.5	86.5	87.7
WEST GEOMETRIC CENTER		91.5	88.5	89.2
VERTICAL	DB 1" ABOVE FLOOR	89.5		
TEMP.	1' " "	92.0		
PROBE	2' " "	92.0		
EAST	4' " "	92.0		
	6' " "	91.5		
	8' " "	92.0		
VERTICAL	1" ABOVE FLOOR	89.5		
TEMP.	1' " "	91.5		
PROBE	2' " "	91.5		
WEST	4' " "	92.5		
	6' " "	92.5		
	8' " "	93.0		
NORTH DB, 4' ABOVE FLOOR		92.0		
SOUTH DB, 4' ABOVE FLOOR		92.0		

REMARKS

SINGLE POINT AIR DELIVERY

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 10 OCT. 63 TIME: 1700 - 1745 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 300 CFM. CFM/OCCUPANT: 3

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	92.25	87.75	89.0
2	92.25	88.0	89.1
3	93.0	89.0	90.1
4	92.25	88.5	89.5
5	92.5	88.5	89.5
6	92.75	89.0	90.0
7	92.25	88.5	89.5
8	92.25	87.75	89.0
9	92.5	88.25	89.4
10	92.5	88.5	89.5
11	93.25	88.75	90.0
12	92.5	88.0	89.1
13	92.5	87.5	89.0
14	92.5	88.25	89.4
15	92.75	88.75	89.8
16	92.25	88.25	89.3
17	92.0	86.75	88.2
18	91.75	88.0	89.0
19	91.5	88.25	89.1
20	91.75	87.5	88.8
21	91.75	87.75	89.0
22	91.75	87.0	88.2
23	91.25	86.5	88.0
AVG. EFF. TEMP.			89.2

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		92.0	77.0	83.0
EXHAUST AIR CONDITION		94.0	90.0	91.0
EAST GEOMETRIC CENTER		92.5	89.0	90.0
WEST GEOMETRIC CENTER		93.0	89.5	90.2
VERTICAL	DB 1" ABOVE FLOOR	89.5		
TEMP.	1' " "	91.5		
PROBE	2' " "	92.0		
EAST	4' " "	92.5		
	6' " "	92.5		
	8' " "	92.5		
VERTICAL	1" ABOVE FLOOR	90.0		
TEMP.	1' " "	92.0		
PROBE	2' " "	93.0		
WEST	4' " "	93.0		
	6' " "	93.0		
	8' " "	93.5		
NORTH DB, 4' ABOVE FLOOR		93.0		
SOUTH DB, 4' ABOVE FLOOR		93.0		

REMARKS

AIR DISTRIBUTED THROUGH EXISTING DUCTWORK.

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 11 OCT '63 TIME: 1315-1350 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 300 CFM. CFM/OCCUPANT: 3

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	91.75	87.0	88.2
2	91.75	87.75	89.0
3	92.5	88.5	89.6
4	91.75	88.5	89.4
5	92.0	88.25	89.1
6	92.25	88.75	89.7
7	91.75	88.25	89.1
8	91.75	88.0	89.0
9	92.0	88.5	89.4
10	92.0	87.75	89.0
11	92.25	88.5	89.5
12	92.0	87.5	88.8
13	91.75	87.0	88.2
14	91.75	88.25	88.2
15	92.0	88.0	89.0
16	91.75	87.75	88.9
17	91.0	85.5	87.1
18	90.75	86.5	87.8
19	91.0	87.5	88.5
20	91.5	87.25	88.4
21	91.0	87.25	88.2
22	91.0	86.0	87.4
23	90.0	85.5	86.9
AVG. EFF. TEMP.			88.6

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		93.0	77.5	83.5
EXHAUST AIR CONDITION		92.5	89.0	90.0
EAST GEOMETRIC CENTER		91.0	88.0	89.0
WEST GEOMETRIC CENTER		92.0	89.0	89.7
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	90.0		
	1' " "	91.5		
	2' " "	92.0		
	4' " "	92.0		
	6' " "	92.0		
	8' " "	92.0		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	90.0		
	1' " "	91.5		
	2' " "	92.0		
	4' " "	92.5		
	6' " "	92.5		
	8' " "	93.0		
NORTH DB, 4' ABOVE FLOOR		91.5		
SOUTH DB, 4' ABOVE FLOOR		92.5		

REMARKS

AIR DISTRIBUTED THROUGH DUCTWORK.

DATA SHEET - - PSDC
VENTILATION STUDIES

SHELTER: 200 PERSON

DATE: 11 OCT '63 TIME: 1545-1615 OBSERVER: SVAERI

TOTAL VENTILATION RATE: 300 CFM. CFM/OCCUPANT: 3

GRID PATTERN READINGS			
LOCATION	DB	WB	ET
1	92.5	87.5	88.9
2	92.5	88.5	89.8
3	92.75	89.25	90.1
4	92.25	89.0	90.0
5	92.5	89.0	90.0
6	93.0	89.5	90.3
7	92.5	89.25	90.1
8	92.5	88.5	89.6
9	92.75	89.0	90.0
10	92.75	88.5	89.6
11	93.0	89.5	90.3
12	92.5	88.25	89.4
13	92.5	88.5	89.6
14	92.5	89.25	90.1
15	92.75	88.75	89.8
16	93.25	88.5	89.9
17	91.5	86.5	88.0
18	91.75	87.0	88.2
19	92.5	88.0	89.2
20	92.5	88.5	89.6
21	92.5	88.0	89.1
22	91.75	86.75	88.5
23	91.0	86.25	87.8
AVG. EFF. TEMP.			89.5

ITEM		DB	WB	ET
SUPPLY AIR CONDITION		93.0	76.5	83.0
EXHAUST AIR CONDITION		93.5	90.5	91.1
EAST GEOMETRIC CENTER		92.0	89.0	89.8
WEST GEOMETRIC CENTER		92.5	90.0	90.6
VERTICAL TEMP. PROBE EAST	DB 1" ABOVE FLOOR	91.5		
	1' " "	93.0		
	2' " "	93.5		
	4' " "	93.5		
	6' " "	93.0		
	8' " "	93.0		
VERTICAL TEMP. PROBE WEST	1" ABOVE FLOOR	90.0		
	1' " "	92.0		
	2' " "	92.5		
	4' " "	93.0		
	6' " "	93.0		
	8' " "	93.5		
NORTH DB, 4' ABOVE FLOOR		93.0		
SOUTH DB, 4' ABOVE FLOOR		93.0		

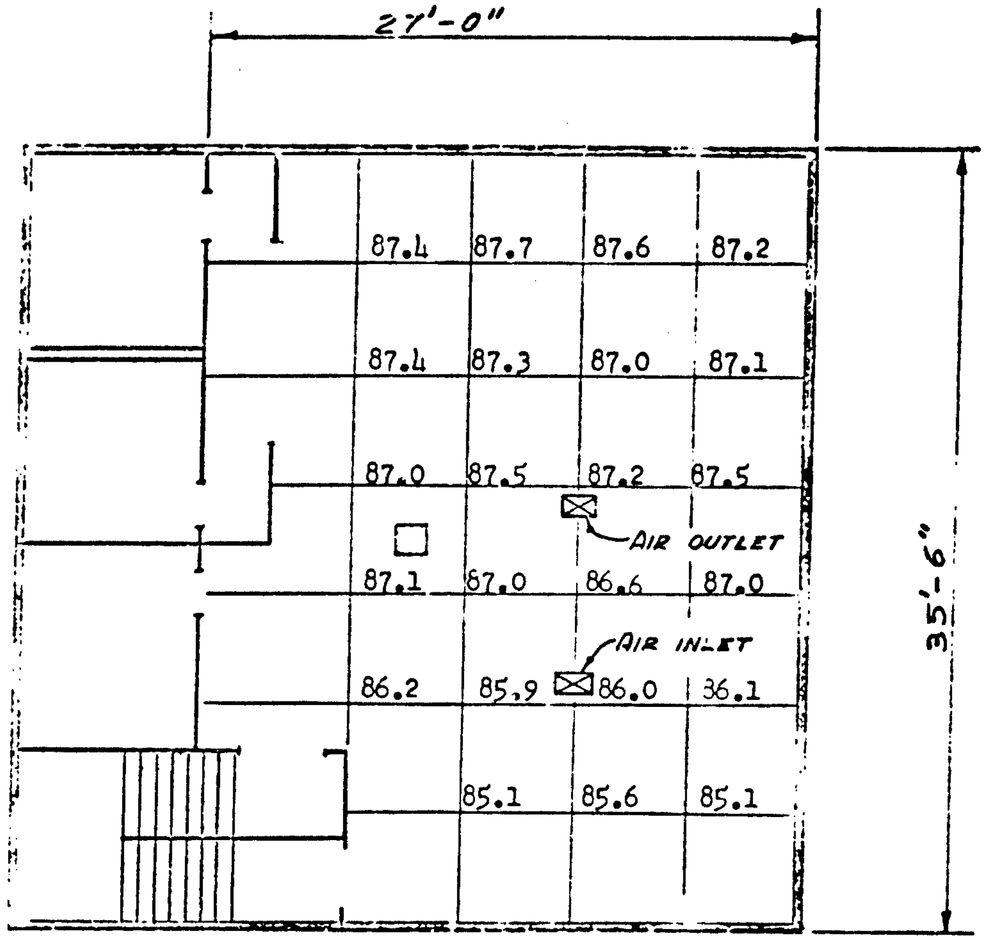
REMARKS

AIR DISTRIBUTED THROUGH DUCTWORK

APPENDIX B

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER – P.S.D.C.



DATE 27 Sept. 63 TIME 1630 - 1700

* VENTILATION RATE 600 CFM or 6 CFM/OCC

AIR SUPPLY COND. 91.6 D.B. 79.0 W.B. 84.0 E.T.

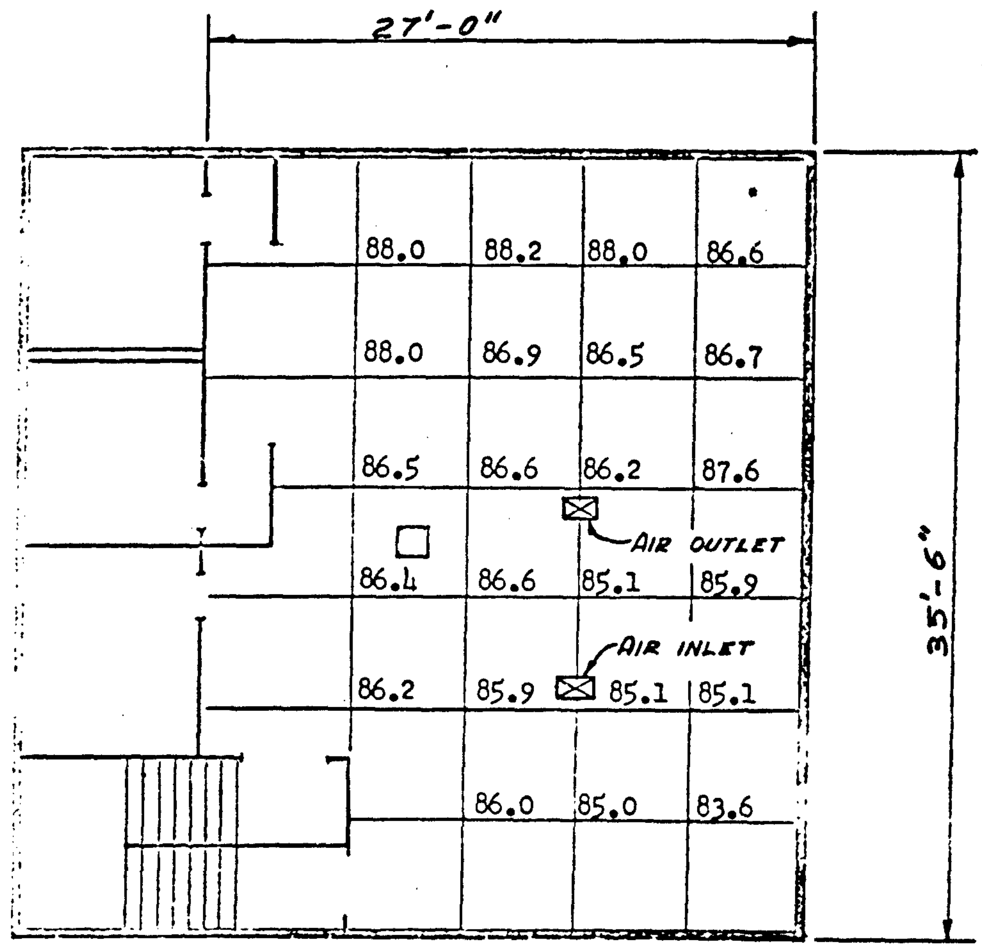
AIR EXH. COND. ______ D.B. ______ W.B. ______ E.T.

REMARKS.

* Just changed from 3 CFM/OCC at approx. 1545 hrs.

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER – P.S.D.C.



DATE 1 Oct. 63 TIME 1730 - 1815

VENTILATION RATE 893 CFM or 8.93 CFM/OCC

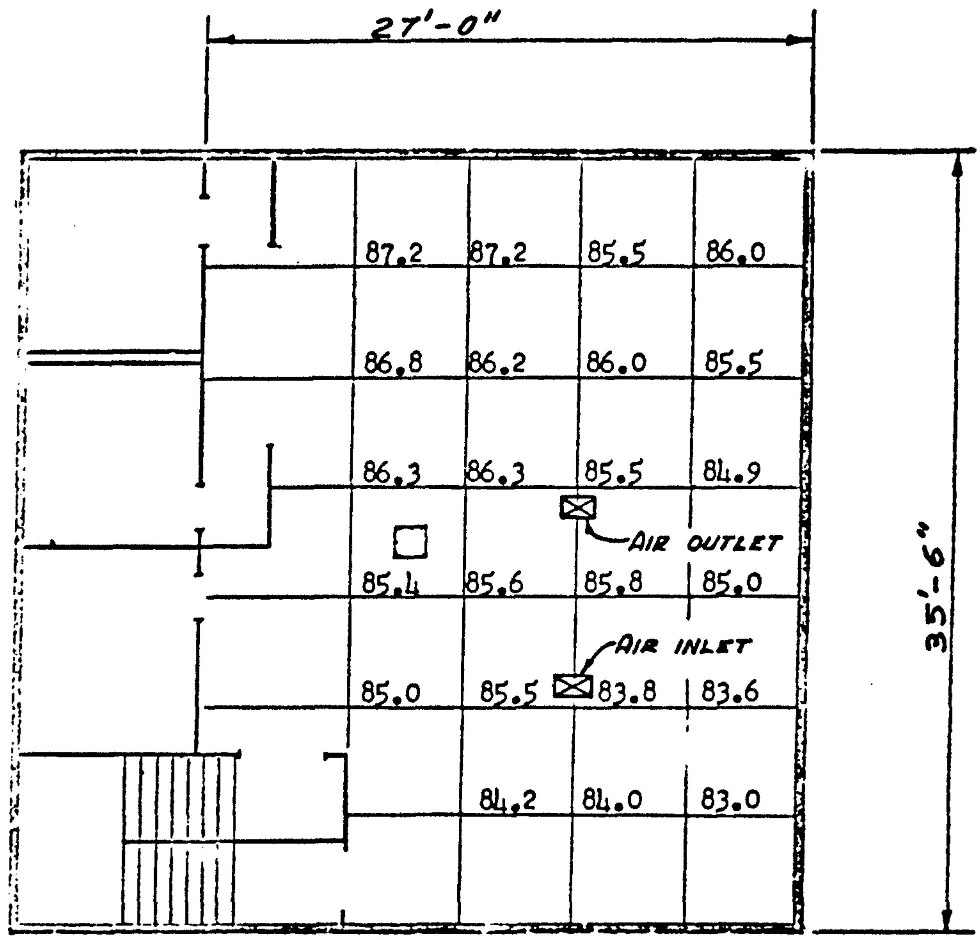
AIR SUPPLY COND. 90.0 D.B. 78.0 W.B. 82.8 E.T.

AIR EXH. COND. 91.5 D.B. 83.5 W.B. 86.1 E.T.

REMARKS.

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER — P.S.D.C.



DATE 3 Oct. 63 TIME 1330 - 1400

VENTILATION RATE 1800 CFM or 18 CFM/OCC

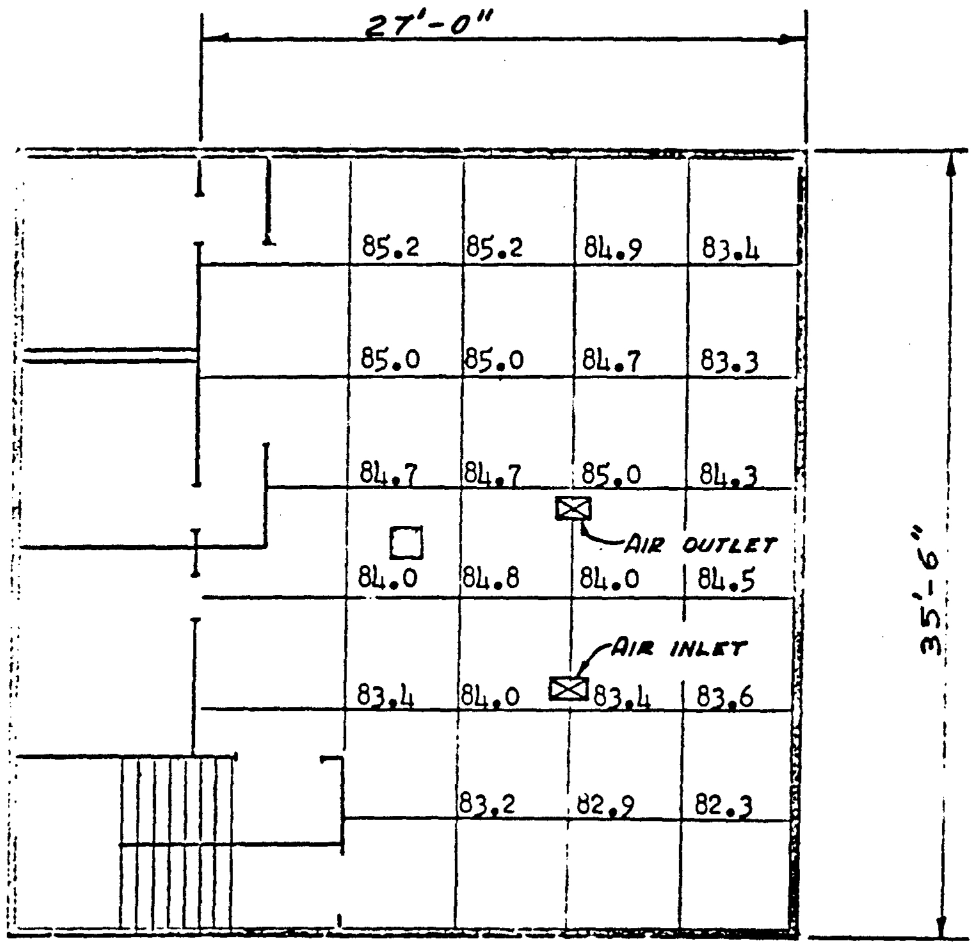
AIR SUPPLY COND. 93.5 D.B. 80.0 W.B. 85.0 E.T.

AIR EXH. COND. 91.0 D.B. 82.0 W.B. 85.1 E.T.

REMARKS.

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER — P.S.D.C.



DATE 5 Oct. 63 TIME 1500 - 1545

VENTILATION RATE 2700 CFM or 27 CFM/OCC

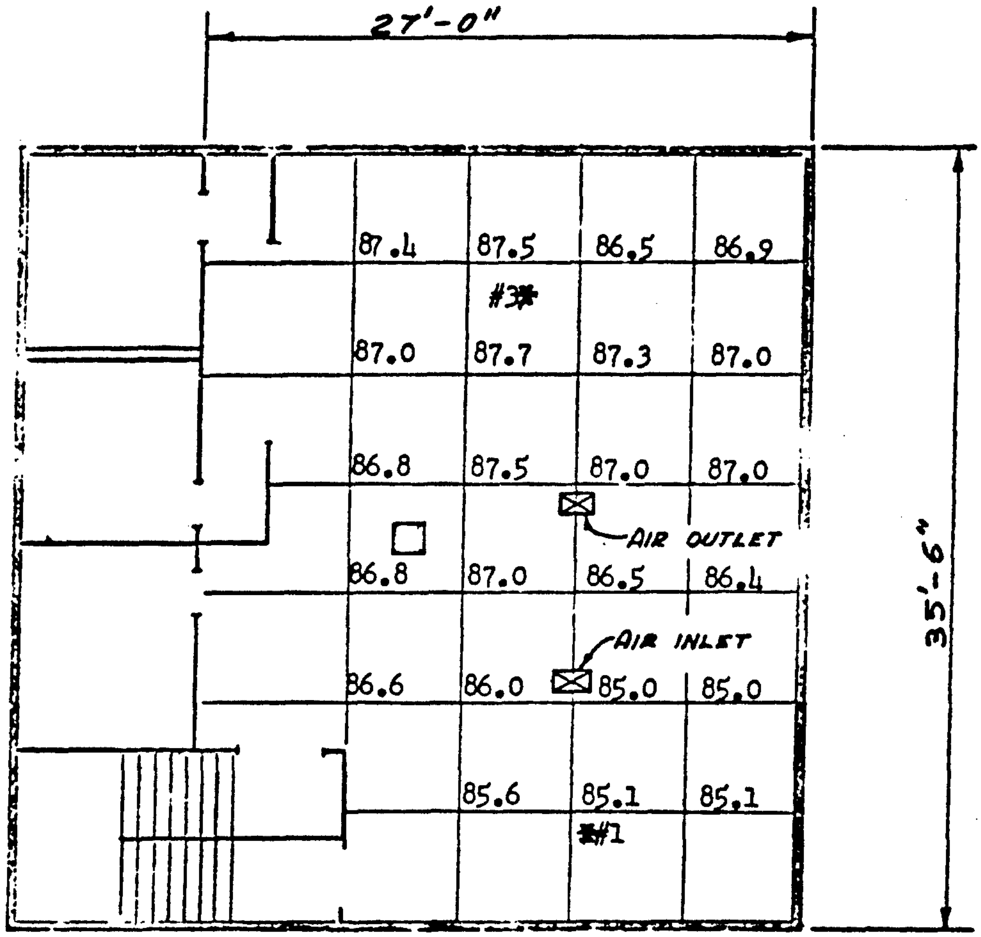
AIR SUPPLY COND. 93.0 D.B. 77.5 W.B. 83.6 E.T.

AIR EXH. COND. 90.5 D.B. 79.5 W.B. 83.7 E.T.

REMARKS.

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER – P.S.D.C.



DATE 9 Oct. 63 TIME 1530 - 1600

VENTILATION RATE 3 CFM per occupant

AIR SUPPLY COND. 92.5 D.B. 78.0 W.B. 83.6 E.T.

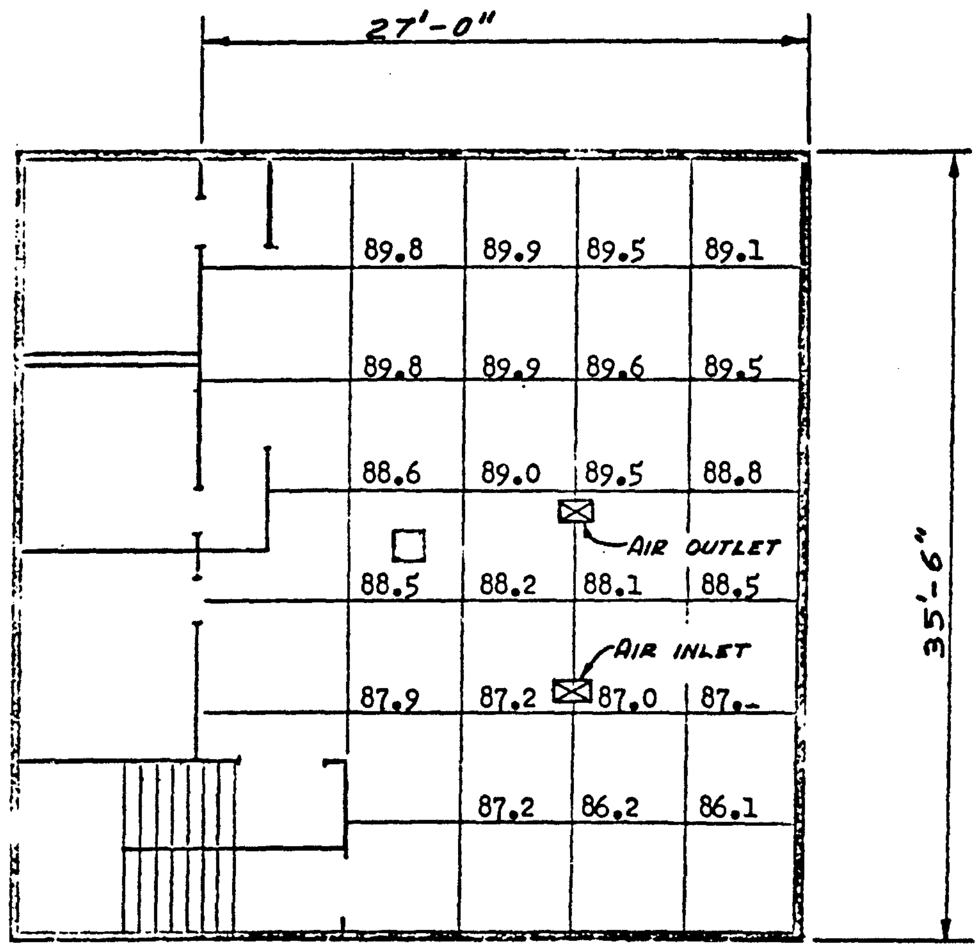
AIR EXH. COND. 93.0 D.B. 85.0 W.B. 87.5 E.T.

REMARKS. * pumps # 1 & 3 dry, 27 simocs dry

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN

200 MAN SHELTER — P.S.D.C.



DATE 10 Oct. 63 TIME 1345 - 1420

VENTILATION RATE 3 CFM/OCC

AIR SUPPLY COND. 92.5 D.B. 79.0 W.B. 84.0 E.T.

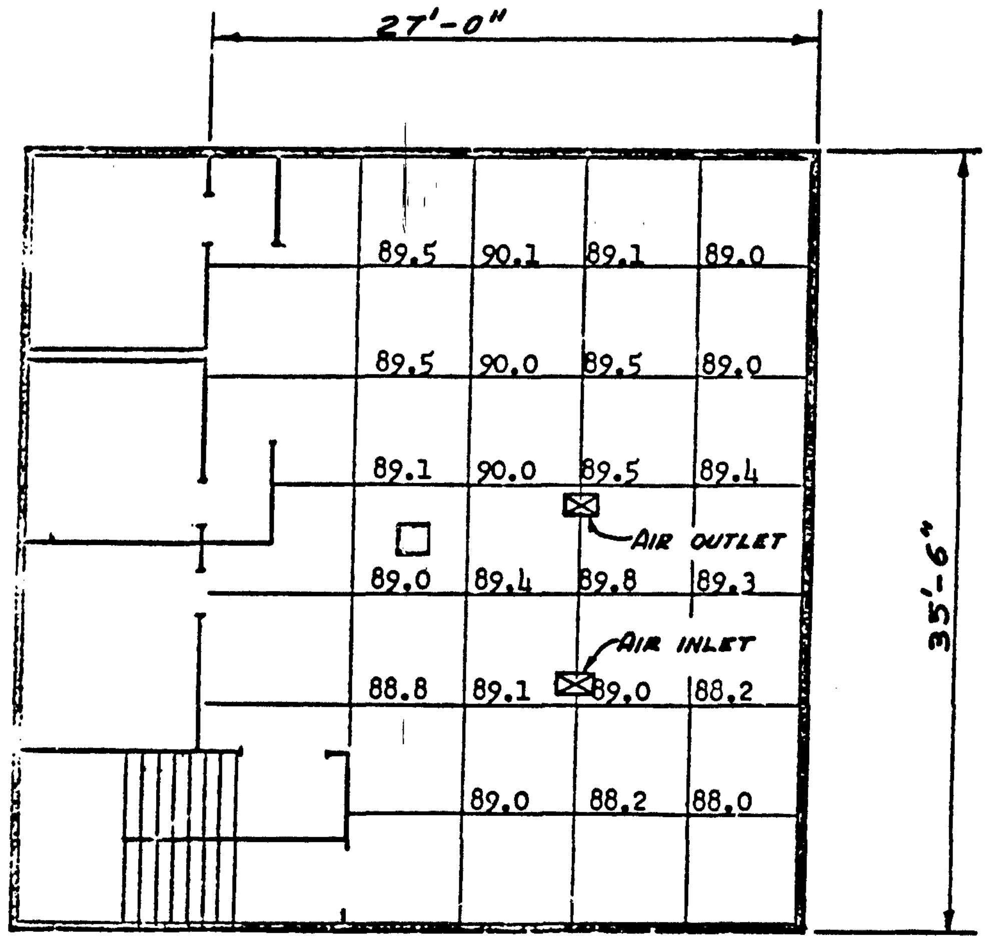
AIR EXH. COND. 92.5 D.B. 88.5 W.B 89.6 E.T.

REMARKS.

EGC	90.5	86.5	87.7
WGC	91.5	88.5	89.2

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN
200 MAN SHELTER — P.S.D.C.



DATE 10 Oct. 63 TIME 1700 - 1745

VENTILATION RATE 3 CFM/OCC

AIR SUPPLY COND. 92.0 D.B. 77.0 W.B. 83.0 E.T.

AIR EXH. COND. 94.0 D.B. 90.0 W.B. 91.0 E.T.

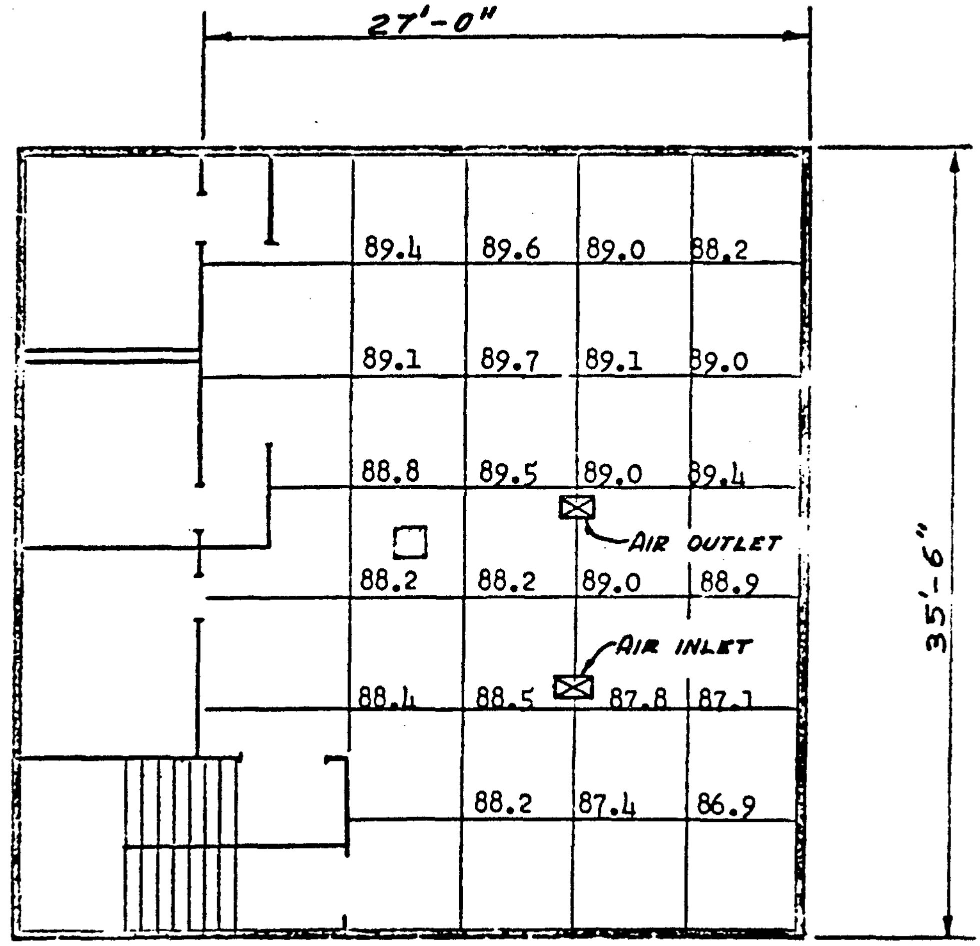
REMARKS.

EGC 92.5 89.0 83.0
WGC 93.0 89.5 90.2
Using duct work

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN

200 MAN SHELTER — P.S.D.C.



DATE 11 Oct. 63 TIME 1315 - 1350

VENTILATION RATE 3 CFM/OCC or 300 CFM

AIR SUPPLY COND. 93.0 D.B. 77.5 W.B. 83.5 E.T.

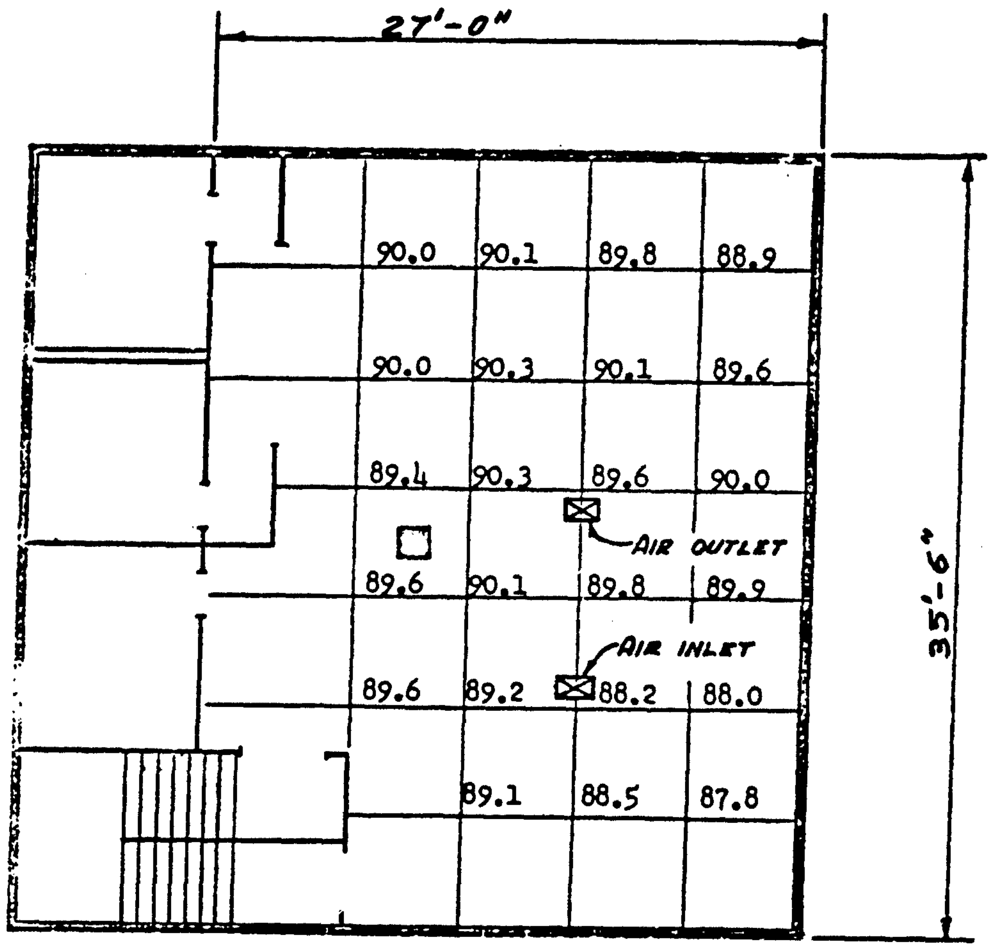
AIR EXH. COND. 92.5 D.B. 89.0 W.B. 90.0 E.T.

REMARKS. Using duct work

EFFECTIVE TEMPERATURE GRID

BASEMENT FLOOR PLAN

200 MAN SHELTER – P.S.D.C.



DATE 11 Oct. 63 TIME 1545 - 1615

VENTILATION RATE 3 CFM/OCC

AIR SUPPLY COND. 93.0 D.B. 76.5 W.B. 83.0 E.T.

AIR EXH. COND. 93.5 D.B. 90.5 W.B. 91.1 E.T.

REMARKS. Using duct work

TABLE II - REGISTER AIR VOLUME DETERMINATION

Register No. & Size		8 Point Velocity Traverse (fpm)								Average Velocity (fpm)	Gross Register Area (Ft.^{2})	Area of Deflector Bars (Ft.^{2})	Net Register Area (Ft.^{2})	Air Volume (cfm) (Avg. Velocity x Net Register Area)
		1	2	3	4	5	6	7	8					
1	3½" x 11½"	350	370	300	310	370	400	380	410	362	0.28	0.052	0.228	82.5
2	3½" x 9"	600	350	400	400	450	440	480	500	452	0.23	0.042	0.188	84.8
3	3½" x 11½"	200	140	140	310	370	290	220	320	242	0.28	0.052	0.228	55.1
4	3½" x 11½"	410	370	220	340	340	230	380	430	340	0.28	0.052	0.221	77.4
5	Blocked													Blocked
	TOTAL													299.8 cfm

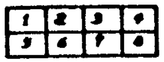
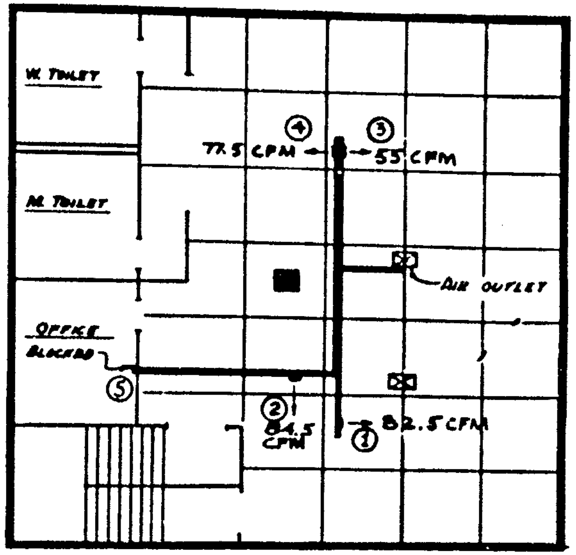


Illustration of 8 point velocity traverse across register face opening using vane type anemometer.

17 deflector bars @ 1/8" x 3½"
Total area 0.052 ft.^{2}

14 deflector bars @ 1/8" x 3½"
Total area 0.042 ft.^{2}

APPENDIX C - Determination of Air Volumes Delivered through Individual Registers in Existing Duct Work



EXISTING DUCT DISTRIBUTION SYSTEM

BASEMENT FLOOR PLAN
200 MAN SHELTER - P.S.D.C.

FIG. NO. C-1